AN

ELEMENTARY TREATISE

ON

PHOTOTOPOGRAPHIC METHODS

AND INSTRUMENTS

INCLUDING A CONCISE REVIEW OF EXECUTED PHOTOTOPOGRAPHIC SURVEYS AND OF PUBLICATIONS ON THIS SUBJECT

BY

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PREFACE.

LIGHT-RAYS, in addition to their heating and illuminating qualities, have a chemical or so-called "actinic" power, characterized by a general tendency to decompose certain chemical compounds, some of which, for that very reason, being utilized in photography.

The term photography, composed of two Greek words phos, or phota, and grapho, means light-drawing or sun-picture, and a photograph may be defined as a picture produced by the actinic action of light-rays (emanating from the object to be pictured) upon a surface chemically prepared for this particular purpose.

Although the origin of photography may be ascribed to the alchemists of the sixteenth century, who had observed that chloride of silver becomes blackened when subjected sufficiently long to the action of light-rays, still, photography as we know that art to-day is not so very old.

In 1777 the Swedish chemist Scheele discovered that the intensity of the actinic power of light-rays changed with the quality of the light, inasmuch as argentic chloride would turn black quicker when exposed to the rays of the violet end of the solar spectrum.

Wedgewood and Davy probably produced the first "sun-pictures" obtained by the action of light-rays upon surfaces

sensitized with nitrate of silver. Their pictures, however, were not permanent—they were not "fixed."

Joseph Nicephore Niepce produced the first permanent sun-pictures in 1814 by a process known under the name of heliography, and in 1824 Daguerre commenced his researches and experiments which eventually (after Niepce and Daguerre had formed a copartnership in 1829) led to the perfection of the so-called "daguerreotype."

In 1839, while alluding to the details of the daguerreotype process before the Chamber of Deputies, in Paris, Arago declared: ... "Nous pourrions, par exemple, parler de quelques idées qu'on a eu sur les moyens rapides d'investigation, que le topographe pourra emprunter à la photographie." ...

Gay Lussac expressed himself in a similar manner when he had occasion to refer to the possibilities in adapting photography to topographical surveys. At about the same period, or possibly a little earlier, Fox Talbot read a paper on photogenic drawings before the Royal Society in London, describing his method for obtaining silhouettes, or shadowgraphs, of objects on paper that first had been treated with a solution of common table salt, then dried and immersed in a solution of nitrate of silver. The salt absorbed by the paper converts a part of the nitrate of silver deposit into chloride of silver, some of the silver nitrate remaining unaffected in the paper. Talbot fixed these silhouettes on the paper by treating the outline pictures with a solution of bromide of potassium.

In 1841 Talbot had perfected his method to reproduce objects in general, and his method thereafter became known as the Calotype or Talbotype.

In 1851 Scott Archer introduced the so-called "wet collodion process," which remained in general use during the following twenty-five years. The wet collodion process required the plates to be coated immediately before use, first with collodion iodide and again with the sensitizing silver bath, and immediately after exposure they had to be developed and fixed. For

outdoor photography a dark-tent or a dark-room wagon had to be provided and the necessary chemicals had to be carried along in the field, together with the camera, plates, and plate-holders. The old photographic cameras, moreover, were unwieldy and cumbersome, and to apply photography on exploring expeditions and travels generally required such an increase in baggage, not to mention the need of special expert knowledge in photographic chemistry, that amateur photography was practically unknown during the period when the wet-plate process flourished.

All these difficulties, restricting the practice of photography to professionals, were overcome when, in 1871, Dr. Maddox discovered the so-called "dry-plate process" and published the details of his "gelatine-emulsion dry-plate coating" for photographic plates.

Dr. Maddox had succeeded in preparing an emulsion of bromide of silver in gelatine, with which plates could be coated and dried in the dark-room until the film had become quite hard, such plates remaining sensitive to the action of light-rays long after the sensitized film had been applied. The present general popularity of photography and its extensive application in various branches of the sciences as well as in the arts dates from Dr. Maddox's invention, which, in 1873, was improved by Kennett.

Collodion has now been entirely replaced by gelatine for all outdoor work and gelatino-bromide dry-plates are manufactured in large quantities and in such variety as to answer all demands and requirements of the different applications of photography of the present day.

The method of photographic surveying as developed by Col. A. Laussedat, who in his first experimental work used the "camera clara," now became more widely known and Laussedat's methods found practical application in several countries, where they now receive a general recognition as valuable adjuncts to the instrumental topographic methods.

Notwithstanding the recent rise in favor of photography,

applied to the sciences in general and to topographic surveys in particular, we still meet with many surveyors who seriously question the practical value and general accuracy of photographic surveys, either from misconception of their guiding principles, from defective results so often obtained from a mere mechanical application of phototopographic rules and methods, or more frequently still, from extreme conservatism.

Others, again, may have failed to become interested in photographic surveying, believing that a thorough familiarity with the theories and laws of optics, photochemistry, descriptive geometry, perspective and general cartography are essentials without which no practical knowledge and understanding of photographic surveying may be obtained.

It should, of course, be admitted that such knowledge will enable the student to master phototopography in a rapid and easy manner, giving him an unquestioned advantage in, and an enlarged field for, the practical application of photography to surveying, or in teaching photogrammetric methods to others, yet the fundamental principles underlying these methods are so simple that it is believed any topographer (with the knowledge that he should have as such) may readily acquire enough of the theory to become fully able to apply photography quite successfully to practical surveying, especially if he is familiar with the methods of the plane table.

This treatise has been written primarily with a view towards overcoming some of the existing prejudices against photographic surveying, and if it aids to demonstrate that this branch of surveying may rightly be assigned a legitimate place in the curriculum of every modern topographer, filling as it does a particular gap in the general series of topographic methods heretofore recognized, its existence will be justified.

In the following pages reference will be made chiefly to those photogrammetric methods which find application to topographic surveys, although the same principles are also used when applying photography to:

Geological Surveys, made for the study of volcanic eruptions and their effects; for the study of recurrent changes in sand-dunes caused by winds blowing from certain directions at regular intervals; for noting changes in glaciers (glacial motion or variation), based upon the comparison of glacier maps and photographs obtained at stated time intervals from identical and fixed camera stations, etc.

Meteorological Observations, for the study of the higher air-currents and cloud altitudes, based upon iconometric cloud charts obtained from photographic plates exposed at two or more stations (simultaneously) at stated time intervals; for the study of the paths of lightning, their lengths, forms, etc.

Hydrographic Surveys, for the location of rocks, buoys, current floats, etc.; for the study of fluvial currents, riparian changes due to corrasion, erosion, shoaling, or silting, etc.; for obtaining coast views from points marked on the charts to serve for future determinations of the positions of vessels that may sight the land from the same locality in regions where fogs prevail; for preliminary surveys of coastal belts while conducting a hydrographic survey of the coast, harbors, etc.

Engineering Works, for estimating the amount of work accomplished at any date, based on photographic records showing the status of the work at specified dates, excavations, cuts, fills, structural buildings, etc.; for preliminary surveys to be used for the location of roads, irrigation dams, canals, etc.

Architectural Surveys, for constructing the ground plans and elevations of old buildings from their photographs; for purposes of renovation, remodeling, publication, etc.

Military and Secret Surveys, for establishing the positions of the enemy's forces; for locating fortifications; for establishing range lines for artillery use; for obtaining topographic reconnaissance maps, etc.

This treatise will indicate, in a general way, how photography may be applied to topography by describing the simple processes and methods, particularly those of a graphic character, that will

suffice to direct beginners in their practical application, leaving it to experience and subsequent special study to determine the measure of success, the more so as several excellent works on this subject have been published recently in the English, French, German, Spanish, and Italian languages.

Preference should be given to the graphic solution of iconometric problems, inasmuch as topographic maps are primarily graphical records of instrumental measurements made in the field for locating the principal points of the terrene. Artificial details and topographic features are largely sketched, or interpolated, when using the ordinary topographic surveying methods, whereas this sketching may be reduced to a minimum when applying photogrammetric methods by determining an increased number of points that control the characteristic horizontal and vertical changes in the terrene, which, in this case, are located graphically upon the chart by means of iconometric transfers from the photographic perspectives of the landscape.

The main control for a phototopographic survey should, of course, be of trigonometric origin and the coordinates of the triangulation points should be computed with a degree of accuracy commensurate with the degree of precision attained in the field observations.

The writer, having consulted all available publications on phototopographic methods and instruments in use, gladly acknowledges his indebtedness for valuable information on this subject to Col. A. Laussedat, Director of the Conservatoire des Arts et Métiers, Paris; Capt. E. Deville, Surveyor-general of Dominion Lands, Ottawa, Canada; Dr. W. F. King, Alaskan Boundary Commissioner to H. M., Ottawa; Signore L. P. Paganini, Engineer Geographer of the Military Geographical Institute of Italy; Dr. R. Doergens, Prof. of Geodesy, Royal Technical High School, Charlottenburg, Prussia, and particularly to the following publications:

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CONTENTS.

CHAPTER III.

PIN-HOLE PHOTOGRAPHY.

CHAPTER IV.

FUNDAMENTAL PRINCIPLES OF ICONOMETRIC MAP-PLOTTING ("ICONOMETRY").

CHAPTER V.

PHOTOGRAPHS ON INCLINED PLATES.

CHAPTER VI.

PHOTOTOPOGRAPHIC SURVEYING METHODS.

CHAPTER VII.

CAMERA LENSES.

CHAPTER VIII.

PHOTOGRAMMETERS OR PHOTOGRAMMETRIC INSTRUMENTS.

CHAPTER IX.

PANORAMA CAMERAS.

CHAPTER X.

ICONOMETERS AND PERSPECTOGRAPHS.

CHAPTER XI.

PHOTOGRAPHIC OPERATIONS IN THE FIELD.

CHAPTER XII.

CONCLUSION AND REMARKS ON THE PRECISION OF THE "POLAR ICONOMETRIC METHOD" AND GENERAL REMARKS ON TELEPHOTOGRAPHY.

PHOTOTOPOGRAPHIC METHODS AND INSTRUMENTS.

INTRODUCTION.

TOPOGRAPHY is that branch of surveying which pictures sections of the earth's surface, in reduced scale, as a horizontal projection, showing the relative positions of points of the terrene in both the horizontal and vertical sense. Under topography, in the closer sense, we generally understand the representation of the terrene in the form of charts, drawn to the scales of 1:5000 to 1:100000, showing not only the relative positions of characteristic points of the earth's surface, but also clearly delineating all natural and cultural details. Topographic charts on scales smaller than 1:100000 partake of a geographic character, while surveys on scales larger than 1:5000 are generally made for special technical purposes.

The works of filling in the details, topographic surveying in the closer sense, may be accomplished by various methods, differing in the matter of cost, time, and attainable accuracy. One may be employed with advantage for one class of work, while another may be preferable for another class, another locality, or, to meet different conditions. The method best adapted to any particular region should be employed to obtain the best results.

The more important methods with their instrumental outfits are:

First—The direct plotting to scale, in the field, of all features that are to be shown on the chart,

A—with a plane table and telemeter or stadia rods;

B—with a tachygraphometer and stadia rods;

C—with either of these instruments, but with a leveling instrument in addition, for locating the horizontal contours;

D—using an aneroid barometer in place of the level.

Second—The compilation of all available data (cadastral surveys, public land, and county surveys, railroad and canal surveys, etc.), giving principally the horizontal distances, a supplementary survey being made to furnish the missing data, which in this case are principally elevations. They may be supplied by trigonometric or spirit leveling, by interpolation and sketching.

Third—The records of the survey may be obtained in the shape of field notes and sketches ("tachymetry"), the map being produced by plotting the recorded data in the office.

A—with a surveyor's compass and steel tape the relative positions of characteristic points may be located in the horizontal sense, while their relative elevations may be obtained by means of a level, minor details being largely sketched;

B—with a transit and steel tape points are located, both geographically and hypsometrically, minor details are sketched;

C—with a transit and stadia rods;

D—with a tachymeter and stadia rods, elevations being obtained automatically;

E—adding a leveling instrument for locating horizontal contours;

F—using a specially constructed aneroid barometer ("Goldschmidt's"), in place of the level for locating and tracing the contours in the field.

Fourth—The field records for developing the terrene are represented by photographic negatives, taken under special conditions from stations of known positions and elevations,

A—with a camera or phototheodolite, using telemeters or other distance measures for obtaining the lengths of base lines and a barometer for ascertaining the elevations of tertiary points;

B—with a surveying camera, separate transit, telemeters, and barometer;

C—with a photographic plane table and distance-measuring alidade, using a barometer for obtaining the elevations of detached camera stations;

D—with a surveying camera, separate plane table, distance measure, and aneroid barometer;

E—with a specially constructed phototheodolite, the iconometric plotting being done with the Zeiss stereo-comparator;

F—with cameras designed to be used attached to kites, to free or to captive balloons.

Minute and detailed methods with ensuing accurate results should be applied to the surveys of cities and all densely settled regions, to the coastal belts, large river valleys, and lakes, particularly when navigable, and this work should be plotted on a large scale.

Arid, barren, and mountainous regions as well as prairies and swamp lands, when sparsely settled, should be generalized in their cartographic representations and they should be plotted on a small scale.

In exemplification of the preceding suggestions we may refer to the new topographic survey of Italy, where Paganini's results not only fully proved the efficiency of photography applied

to surveys of alpine regions (plotted in 1:25000 and 1:50000), but also led to the adoption of the phototheodolite as an auxiliary instrument to the plane table. The latter was used for mapping the areas below 2000 m. in altitude, while the phototheodolite was depended on to delineate the terrene lying above that altitude.

After the area which is to be surveyed has been covered with a net of triangles and polygons it will have been provided with a framework of lines of known lengths and directions (being in itself a skeleton survey of the country), and after the natural details and artificial features have been filled in, by one of the numerous topographic methods with more or less details and accuracy, we will have a topographic survey of the area of more or less precision.

The number of so-called control points for a given area, determined in elevation and geographical position during a topographic survey, should be increased in the same ratio as the degree of accuracy, required for the survey, and also as the amount of details, conditioned by the scale of the survey, may be increased.

Photography has been extensively applied to surveys of rugged mountain regions in Italy, Austria, Russia, Canada, and Alaska with great success. The phototopographic method, originally devised by Colonel Laussedat, found its first application in France and in Germany. In its early stages it was practiced exclusively under governmental and military auspices, being primarily used for so-called secret and military surveys. Lately, however, phototopography has found a wider and more general application also in France and Germany.

More recently photographic surveys have been executed in Greece, Spain, Portugal, Norway, Belgium, Mexico, Chile, Peru, Brazil, Argentine Republic, Switzerland, Australia, England, Africa, and more recently still in the United States, although Lieut. Henry A. Reed has, for several years past, taught photographic surveying, theoretically and practically, at the U. S. Military Academy at West Point.

CHAPTER I.

SHORT REVIEW OF EXECUTED PHOTOGRAPHIC SURVEYS AND LISTS OF THE MORE IMPORTANT PUBLICATIONS ON PHOTOGRAMMETRY AND PHOTOTOPOGRAPHY.

I. Photographic Surveying in France.

Practical results from the early application of photography to surveying failed to materialize for some time, partly owing to the slowness and uncertainty of the old photographic process, and partly due to the greatly increased efficiency of surveying instruments and methods in general.

The chances of utilizing landscape perspectives for a geometrically true representation of the terrene in horizontal plan became realized by the combination of surveying instruments with the modern camera (with the reliable, uniform, and quick dry-plate process). Of course, it is not necessary to merge the camera and the geodetic instrument into a single apparatus. For facilitating transportation and for other reasons they are frequently used separately over the same station.

The theoretical principles upon which photogrammetric methods are primarily based were known to J. H. Lambert (of Zurich), who published a work on perspective in 1759, in which reference is made to those identical principles. Still, Lambert's suggestions were neither followed nor were his theories given a practical application in this respect, until the well-known savant and hydrographer Beautemps-Beaupré, while on a scientific expedition, in 1791 to 1793, made a series of free-hand sketches of the regions skirting the shores of Van Diemansland (Tasmania) and of Santa Cruz Island. After his return to France he attempted

the first practical application of Lambert's theory by constructing topographic reconnaissance maps of the coastal regions just referred to, based upon the outline sketches of the terrene.

Beautemps-Beaupré subsequently made frequent reference to the feasibility of his cartographic methods, recommending them particularly to explorers. Little or nothing, however, was undertaken by others toward improving Beautemps-Beaupré's new cartographic method, and it had practically fallen into oblivion when Arago, in 1839, called attention to the possibilities of photography when utilized in this connection.

Beautemps-Beaupré's suggestions probably met with so little favor because it is not easy to make free-hand sketches of landscapes geometrically accurate enough to be used iconometrically in place of the landscapes. Iconometry as applied to topographic plotting rests upon the same principles as the plane-table method of determining points by the intersections of lines of direction, drawn to such points from known stations, only in iconometry such lines are graphically deduced from the photographic perspectives and are drawn in the office.

Apparently Capt. Leblanc, of the French Génie Corps, made the only applications of Beautemps-Beaupré's method, in antecedence of the year 1849, principally in connection with military surveys.

Col. A. Laussedat had taken up the study of iconometric map-plotting in 1850. In the early part of his investigations he utilized a "camera clara" (invented by Wollaston in 1804) for obtaining the necessary perspectives of the terrene, tracing their outlines by hand. In 1852, however, he replaced that instrument by the "camera obscura" (invented by Dom Panunce, or by some attributed to G. della Porta). Laussedat's camera obscura was modelled after Niepce's, but it was supplied with special surveying devices.

Subsequently as Chef du Génie Corps, Laussedat executed numerous experimental surveys, improving the surveying camera and elaborating the methods. In 1858 he obtained a Bertaud

lens, which was practically free from aberration and which he used for the new phototheodolite made by Brunner in Paris.

In 1859 Laussedat felt justified, by the good results he had obtained with this improved phototheodolite, to announce the successful application of photography to surveying to the Academy of Sciences in Paris. After a critical examination of Laussedat's methods and results, by Daussy and Laugier, these two members of the Academy approved and endorsed his methods. Laussedat also made a few topographic maps with the aid of balloon-photography, but soon returned to the exclusive use of the station-camera.

At the exposition of 1867, in Paris, Laussedat exhibited the first known phototheodolite and some map specimens, based upon photographic surveys, among others a plan of Paris (scale 1:6666) which compared very favorably with one that Emmery had made in 1839 by means of instrumental surveys. The survey for the phototopographic map of Faverges in Savoy, scale 1:5000, was executed in 1867 by Capt. Javary and Lieut. Garibaldy, of the Génie Corps, under Col. Laussedat's direction, and it was based on 120 photographs. It covered an area of about three square miles and the topography was controlled by about 5000 points that had been identified on the pictures and which were plotted iconometrically on the chart.

Col. Laussedat's work in this field has been so complete that the guiding principles which he first laid down and subsequently elaborated by numerous practical applications are still in use, and his interest in this work continues unabated to this day.

From 1851 to 1871 Col. Laussedat and his associates in this work were frequently called away from the pursuance of phototopographic surveys, having other duties assigned them, and we find that Laussedat's surveying methods did not become generally known in France, and it was left to scientists and engineers of other countries (Germany and Austria) to popularize this surveying method and extend its application to various branches of the sciences.

In 1858 Chevallier had an instrument patented under the name "planchette photographique" which soon found much favor, especially among members of the Génie Corps. This photographic plane table is described by Alophe ("Le passé, le présent et l'avenir de la photographie," Paris, 1861), by d'Abbadie ("Bulletin de la Société de Géographie de Paris," 1862), by Paté ("Application de la photographie à la topographie militaire," Paris, 1866), by Col. A. Laussedat ("Recherches sur les Instruments, les Méthodes et le Dessin topographiques," Paris, 1898), and others. It was manufactured by Dubosque, in Paris, and used by Wiganowsky, Paté, and A. Jouart.

Martens, in Paris, was probably the first to devise a "panoramic camera" (1847), in which he used a cylindrically bent daguerreotype plate.

Inclined plates for phototopography were also used at an early date in France, notably by Th. Pujo and T. Fourcade, who published their methods, under the title "Goniométrie Photographique," in Les Mondes, No. 4, 1865.

France had an interesting exhibit at the World's Columbian Exposition in Chicago, 1893, showing photographic surveying instruments and map specimens, in illustration of topographic and astronomical results, gained chiefly under the direction of Col. A. Laussedat and taken from the collections of the Conservatoire National des Arts et Métiers, Paris, of which institution Col. Laussedat is now director.

In recent years balloon surveying has been resumed in France under the auspices of the Ministry of War, the camera being used in connection with both the free and captive balloon. Balloon surveying had been rather neglected, notwithstanding the good results which had been obtained in the early stages of photographic surveying in Paris by Col. Laussedat and Nadar (1866).

Long-distance photography ("telephotography") seems to have been first studied in France by Lacombe and Matthieu. A résumé of their results has been embodied in an official report to the French Government in 1887 by Commandant Fribourg,

recommending the adoption of telephotography as a reconnoitering method in the Génie Corps.

Guillemont and Jarret followed in the lines laid down by Lacombe and Matthieu, but little reached the general public regarding the practical results obtained by this method in France. Still, it is now well known that the French officers stationed at Grenoble have obtained excellent results in telephotography as applied to military reconnaissance, showing the operations and the disposition of troops in the field, depicting the effects of cannon-shots upon bombarded fortifications, etc. The telephotographic negatives obtained at Grenoble clearly define objects at distances from 2 to 6 km. The French telephotographic cameras are mostly made by Hondaide and Derogy in Paris.

In 1893 H. Vallot commenced the mapping of the Mont Blanc mountain group and its immediate vicinity. He is assisted in this work by J. Vallot, who, in 1890, founded a meteorological observatory on Mont Blanc. This map is being drawn in 1:20000 scale and the greater part of the topography is based on photographs.

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II. Photographic Surveying in Germany.

Col. Laussedat's photographic surveying methods soon found admirers and earnest students in Germany and Dr. A. Meydenbaur became an early exponent of this method. Some writers even claim that, in 1858, while Meydenbaur was engaged with obtaining the measurements that were needed for planning the renovation of the cathedral at Wetzlar, he had, independently of Col. Laussedat's work, conceived the idea to utilize photographs of the building to arrive at the dimensions of inaccessible details.

General von Alster repeatedly recommended in his official reports that experimental surveys be inaugurated by the Prussian Government, to familiarize the officers of the General Staff with the photographic surveying methods, but the war of 1866 prevented action being taken in this direction. Still, Count von Moltke, Chief of the Prussian General Staff, had soon recognized the value of such methods for military and secret surveys, and before the next war took place (which was the Franco-Prussian war of 1870–71), a complete military phototopographic detachment had been formed and organized. In 1870 this reconnoitering corps was placed under the command of Capt. Bernhardi and Lieut. R. Doergens, who furthermore had the

assistance of the civil photographic experts Hintze, Quidde, and Schmier.

During the siege of Strassburg this corps made a survey of a part of the city and the near-by fortifications, plotting the work in 1:2500 scale, but the early surrender of the city made it unnecessary to finish the survey. Only a few ranges as obtained by this survey had been utilized by the army, principally to concentrate the bombardment to certain districts, sparing others, especially the noble cathedral building. During the iconometric plotting of this map some discrepancies were discovered, which Dr. Doergens ascribed to defects in the camera lens and to the unstable character of the instrument, which had been put together too hurriedly.

No further opportunities were offered during the Franco-Prussian war for other phototopographic surveys and the surveying cameras were subsequently used for obtaining pictures of historically interesting features, of points of strategic importance to be utilized in making corrections and additions to the maps of France which had been distributed among the officers that were directing the movements of the invading German armies.

Probably the first German publication on the subject of photographic surveying may be found in Horn's "Photographische Mittheilungen," April, 1863, being a German translation of Col. Laussedat's explanations given in his lecture, delivered Jan. 9, 1863, before the "Société photographique" in Paris.

In the June number of the same magazine Dr. Meydenbaur published his first article on photographic surveying, in which he makes use of the term "photometrographie". Subsequently this was changed to "metrophotographie" and finally to "photogrammetrie" ("Bildmesskunst").

The March number of Horn's "Photographische Mittheilungen," 1866, contains an article by Dr. Vogel on Johnson's photographic apparatus for making topographic surveys, in which the method for the iconometric determination of horizontal and vertical angles is described.

Since 1882 Dr. Meydenbaur has been the Director of the "Photogrammetric Institute" in Berlin, founded by the Prussian Government for the collection of photographic data to bring the German topographic maps up to date and for the preservation of views of ancient monuments and buildings. Dr. Meydenbaur is now engaged with the publication of "Das Denkmäler Archiv," being a collection of photographic reproductions of buildings of archeological and architectural interest.

Since 1867 a number of photographic surveys have been made under the auspices of the Prussian Ministry of War. The first larger attempt was the topographic survey of Freiburg and vicinity, scale 1:1000, including the architectural survey of the cathedral of the same city.

From 1869 the theory of photographic surveying has been included in the lectures on geodesy (Prof. Doergens) at the Royal Building Academy in Berlin. In 1886, when the new Royal Technical High School at Charlottenburg, near Berlin, had been completed, a special chair (filled by Dr. Pietsch) was set aside for teaching photogrammetry in all its branches, including balloon surveying.

The late Prof. Jordan, as a member of G. Rholf's African exploring expedition in 1873–74, made a phototopographic survey of the "Oasis Dachel," including the settlement "Gassr-Dachel," in the Libyan Desert. (Jordan, "Vermessungskunde," Vol. II, Stuttgart, 1893, and "Zeitschrift fuer Vermessungswesen," Part I, Vol. V, 1876.)

Prof. Jordan fully appreciated the value of photography as an auxiliary to topographic surveys, and he remarks in the article "Ueber die Verwerthung der Photographie zu geometrischen Aufnahmen" (Zeitschr. f. Verm., 1876): . . . "Dasz die Photographie in vielen gewissen Faellen mit ausserordentlichem Vortheil angewandt werden koennte, z. B. bei schwer zugaenglichen Gebirgen und auf Entdeckungsreisen, erscheint beim ersten Blick auf die Sache zweifellos."

The good results obtained by Dr. Meydenbaur in the valleys

of the Reusz (1873) and Rhine (1876) considerably increased the number of advocates for phototopography in Germany.

Dr. Stolze in 1874, while a member of the archæological expedition under F. C. Andreas, used a Meydenbaur camera-theodolite to make a survey of the ruins of Persepolis, of Pasargadæ, and of the ancient temple at Djamhât ("Masdjid i Djamâht") in Shiraz, Persia.

Dr. S. Finsterwalder has made several phototopographic surveys in the Bavarian Alps, including surveys of glaciers, made at stated time-intervals, to ascertain their variations and movements in both the horizontal and the vertical sense. During the summer months of 1888 and 1889 he surveyed the "Vernacht" Glacier in the valley of the Oetz, in Tyrol, having the assistance of Dr. A. Bluemke and Dr. H. Hess; in later surveys he was assisted by Dr. Kerschensteiner.

Dr. C. Koppe has done much literary and practical work in photogrammetry and phototopography. Recently he has published the description of his new phototheodolite, made by F. Randhagen in Hannover, that may also be used for astronomical observations (lat. determinations).

Dr. Meydenbaur, Prof. Jordan, Dr. Doergens, Dr. Stolze, Dr. Schroeder, Dr. Vogel, Dr. Koppe, Dr. Hauck, Prof. Finsterwalder, Prof. Foerster, Dr. Pietsch, Dr. Voigtlaender, and others have contributed largely toward the popularization of the phototopographic methods in Germany.

III. Photographic Surveying in Austria.

Karl Koristka, having made the acquaintance of Messrs. Laussedat and Chevallier in Paris in 1867, became interested in photography applied to surveying, and he probably is the first who made a phototopographic survey in Austria (survey of the city of Prague). Still, the method met with little favor in Austria owing to the inconvenience of the wet-plate process, until, in 1890, the authorities of the Military Geographic Institute, in Vienna,

ordered a series of experimental photographic surveys to be made in the vicinity of Vienna, which fully demonstrated the usefulness of this method for the surveys of certain regions. Among the officers of the Austrian army we may mention Lieut. L. Mikiewicz, Maj. Bock, Maj. Pizzighelli, Lieut. Hartl, Capt. Huebl, and others who have materially aided in the development of photographic surveying methods in Austria.

Since 1889 many engineers have adopted phototopographic methods for the surveys of inaccessible regions, or for regions where the other topographic methods would have been too time-consuming or too expensive. Among these we may cite V. Pollack (Eng'r in Chief of the Austrian Government R.R. System), M. Maurer, F. Hafferl, etc.

Prof. F. Schiffner, Prof. A. Schell, and Prof. F. Steiner (the latter teaches the principles of photographic surveying at the Tech. High School in Prague) have done much as teachers, writers, and propagators in improving phototopographic methods and instruments.

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IV. Photographic Surveying in Sweden.

Swedish meteorologists made use of photographs for the study of cloud formations in 1877, and since then H. Hildebrand Hildebrandson, Director of the Meteorological Observatory at Upsala, has used and recommends the photogrammetric methods for observations to ascertain cloud altitudes and air-currents. Identical points of the same cloud, photographed on two simultaneously exposed plates, may be found at leisure and with a far greater degree of certainty than such points may be located, in nature, by two observers with transits and telephone connection for a mutual guidance toward the selection of identical points for observation.

The first attempt to apply phototopographic methods in

Sweden was probably made by Prof. G. de Geer in 1882, when he, together with Prof. A. G. Nathorst, surveyed some glacial fields in Spitzbergen.

Since 1890 the Swedish General Staff has been actively engaged with phototopographic surveys, notably under the direction of Major Lowison. The field work is conducted very much in the same manner as that executed in Italy under L. P. Paganini, restricting the use of the camera to the mountain regions above timber-line, the valleys and wooded areas being surveyed with the plane table.

Among those who have actively used phototopographic methods in Sweden we may cite Major H. Kinberg, Prof. Rosen, Dr. A. Hamberg, Major N. C. Ringertz, J. Westmann, and others.

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V. Photographic Surveying in Switzerland.

Since 1889 Prof. Becker, Col. Fahrländer, Prof. Amrein, and others suggested the use of photographic methods for bringing the general topographic maps of Switzerland up to a standard to meet modern requirements. The Topographic Bureau finally entered upon a series of experimental surveys to ascertain whether the phototopographic methods had reached that stage of perfection that they should replace the plane-table methods heretofore in use for alpine topography.

A description of the phototopographic experimental surveys, made under the auspices of the Topographic Bureau of Switzerland, may be found in:

M. ROSENMUND. "Untersuchungen ueber die Anwendung des photogrammetrischen Verfahrens fuer topographische Aufnahmen." Fritz Haller. Bern, 1896.

The Topographical Engineer, S. Simon, used the phototopographic method extensively in connection with the preliminary surveys of location for the "Jungfrau" railroad and for improving the terrene representation of some of the General Staff maps of Switzerland.

The following publications bearing on this subject may be cited:

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VI. Photographic Surveying in Italy.

The extensive mountainous regions of Italy are peculiarly well adapted for the application of photography to their topographic surveys and we find that phototopography for several decades past has been practiced in that country with marked success.

Prof. Porro spent much time, labor, and energy towards perfecting the methods and instruments to apply photography to tachymetry and to topography. The results of his investigations, which date back to the year 1853, were published under the title "Applicatione della Fotografia alla Geodesia" (Saldini, Milano, 1855).

Prof. Porro's instruments, which were supplied with sensitized plates of spherical shape ("Fotografia sferica"), have been preserved by Salmairaghi, Director of the Polytechnic Institute in Milan, Prof. Porro having been a member of the faculty of this institution.

With Porro's death further investigations and experiments in phototopography ceased in Italy until the year 1875, when Michele Manzi, an officer of the Military Geographic Institute of Italy, utilized some photographs of views, taken in the Abruzzi Mountains with an ordinary camera, to supplement the topographic details of his plane-table survey of the Gran Sasso group. This attempt gave such gratifying results that the same officer in the following year made a special and more practical application of photography in the topographic survey of Mont Cenis, particularly of the region about the Bart Glacier.

In 1878 Gen. Ferrero, Chief of the Geodetic Department of the Military Geographic Institute, pointed out to the Directory that the resumption of practical tests and experimental surveys in phototopography were very desirable, in view of the advances which had been made in the photographic methods

recently. Phototopography had been suspended in deference to the claims of several members of the Institute that photographic data were too unreliable for topographic purposes, particularly for large scale maps.

In the same year (1878) L. P. Paganini, Engineer Geographer of the Institute, was instructed to proceed to Apua and resume phototopographic survey work, with a view toward ascertaining whether phototopographic surveys would be economical and more expedient, now that such decided advances had been made in both the manufacture of photographic lenses and in the photochemical process.

The practical results of Paganini's investigations and experimental surveys during the period from 1878 to 1879 were so satisfactory that, in 1880, he was directed to begin a systematic phototopographic survey of the area bounded by the valleys of the Orco, the Valsoana, the Cogne, and the Valsavaranche, comprising an area of about 390 square miles. The survey of this mountain complex was finished by Paganini in 1885. In 1884, however, the phototheodolite of the Institute had been replaced by an improved instrument of superior qualities, made by Galileo in Florence after plans and specifications submitted by Paganini and incorporating improvements suggested by the experience gained in the field.

This phototheodolite, model of 1884, has been fully described by Paganini in "La Fototopografia in Italia," Rivista Marittima, Fasc. VI e VII, 1889; also in Rivista di Topografia e Catasto, Nos. 8, 9, e 10, 1889. A German translation, by A. Schepp, of L. P. Paganini's "La Fototopografia in Italia" may be found in the Zeitschrift fuer Vermessung, Nos. 3 and 12, 1891, and No. 3, 1892. A translated extract from Paganini's article has been published in Appendix No. 3, in the Superintendent's Report of the U. S. Coast and Geodetic Survey for 1893.

Paganini's excellent results effectively established the efficiency of phototopography for alpine topography and fully

solved the technical side of the problem. Owing to the untiring efforts of the officers of the Military Geographic Institute toward improving phototopographic methods and instruments, the surveying camera has been adopted as an auxiliary instrument to the plane table, the combined use of both instruments in the new topographic survey of Italy having produced the best results.

The latest improvements to Paganini's camera-theodolite were first described in a report to the First Geographic Congress in Italy. A German extract from that report by Fenner may be found in the Zeitschrift fuer Vermessung, 1893.

The principal departure from the older model (1884) consists in abolishing the excentrically mounted telescope and converting the camera itself into a centrally-mounted telescope by replacing the ground-glass plate of the camera with an opaque plate having a Ramsden eyepiece in its center whenever observations with the telescope are to be made. This new model (1890), having all the details of a theodolite with vertical circle, may be used, whenever the necessity arises, for making angular measurements, in the same way as with an engineer's transit, simply by exchanging the ground glass for the plate with eyepiece, as just mentioned.

This instrument, together with the "photographic azimuth apparatus" designed for hydrographic surveys, has been described by Paganini in "Nuovi Appunti di Fototopografia; Applicationi della Fotogrammetria all' Idrografia, seguiti alla Nota; La Fototopografia in Italia." Publicata nella Rivista Marittima, Roma, E. C. Forzani, 1894.

When the Military Geographic Institute, in 1891, sent some map specimens and phototopographic instruments to the Ninth Geographic Congress in Vienna, in illustration of the Italian phototopographic methods, Col. Robert von Sterneck wrote to the Institute, in the name of the Committee on Awards, that the Italian phototopographic exhibit undoubtedly deserved the first prize. Franz Hafferl, Engineer of Austrian Railways,

wrote: "Votre exposition photogrammétrique est sans comparison la meilleure. Toutes les autres ne sont que des essais plus ou moins manqués de construction d'appareils phototopographiques et des constructions de cartes d'une petite entendue." Dr. S. Finsterwalder (Professor of Mathematics and Photogrammetry in Munich, Bavaria), Vincenz Pollack (Engineer in Chief of the Austrian railroad system), and Col. Otto Krifka (of the Geographic Institute in Vienna) also made commendable reference to the Italian exhibit.

Other publications having reference to the phototopographic work in Italy, besides those already referred to in the preceding paragraphs, may be cited as follows:

GIUSEPPE BERTELLI. "Note ed Appunti di Topografia-Fotografia." Rivista Militare Italiana, Feb., 1884.

Capt. CARLO MARSELLI. "La Foto-topografia applicata alla Construzione della Carta Alpine." Bolletino del Club Alpino Italiano, XXIV, No. 57 1890.

GIACOMO BUONOME. "La Foto-topografia in Africa." Bolletino della Societa Africana, I e II, 1890.

Prof. INNOCENZO GOLFARELLI. "Bolletino della Societa Fotografica Italiana." Firenze, April and May, 1890.

L. BENNATI. "La Fotografia nelle sue Applicazione militare." Rivista d'Artiglieria et Genio, II, 1892.

Col. A. LAUSSEDAT. "Iconométrie et Métrophotographie Notice sur l'Histoire des Applications de la Perspective à la Topographie et à la Cartographie." Paris, Photographe, Sept. et Oct., 1891.

Dr. S. FINSTERWALDER. "Die Photogrammetrie in den Italienischen Hoch-Alpen." Mittheilungen des deutschen und oesterreichischen Alpen-Vereins, No. 1, 1890.

Wochenschrift des Oester. Ing. u. Archit. Vereins, Nos. 21 and 22, 1890.

VII. Photographic Surveying in Spain.

Although an early interest was manifested in photography applied to surveying in Spain, little has been accomplished in the practical application of photogrammetric methods until quite recently.

The Madrid Academy of Sciences, in 1862, offered a prize for the best treatise in answer to the query, What is the best process or method for applying photography to the plotting of maps and plans? Of the answers received the memoir, submitted by Capt. A. Laussedat in 1863, was awarded the prize. This memorandum was accompained by the plan of the village Buc, near Versailles, plotted on 1:1000 scale, together with eight photographic views on which the topography of this plan was based.

In the following year Lieut.-Col. Don Pedro de Zea was commissioned to study the French methods and instruments used in photographic surveying. Lieut.-Col. P. de Zea examined Capt. Laussedat's phototopographic camera (made by Brunner, Paris), Capt. Chevallier's "planchette photographique," Sutton's "panoramic camera" (made by Thos. Ross, London), etc., collating and describing the results of his investigations in:

DON PEDRO DE ZEA. "Las Applicaciones de la Fotografia al Servico militar." Madrid, 1863.

Don Juan Pie y Allué, Mining Engineer, published a phamplet on phototopography, in 1896, in which a specimen survey that he had made in the province of Almeria, plotted on 1:1000 scale, was included:

DON JUAN PIE Y ALLUÉ. "Fotogrametria ó Topografia fotografica." Enrique Teodoro. Madrid, 1896.

A very complete and general work on phototopographic methods, instruments, and executed surveys, including experimental survey specimens made in Spain, has been published by Messrs. C. de Iriarte and L. Navarro, in 1899:

CIRIACO DE IRIARTE y LEANDRO NAVARRO. "Topografia fotografica ó sea Applicacion de la Fotografia al Levantamiento de Planos." Raoul Péant. Madrid, 1899.

VIII. Photographic Surveying in the Dominion of Canada and in Alaska.

Capt. E. Deville, Surveyor-General of Dominion Lands, inaugurated extensive phototopographic surveys in Canada, which from their inception, in 1888, were marked with great success. These surveys were carried out under the auspices of the Canadian Department of the Interior in the vicinity of the Canadian Pacific R.R. in the Rocky Mountains. A special triangulation had been made and a single photographic surveying party of four men (under J. J. MacArthur) covered an average area of 500 square miles per annum until 1892. The winter months of each year were spent in Ottawa with plotting the photographic data collated in the preceding season (under the direction of Capt. Deville) on a scale of 1:20000.

At the World's Columbian Exposition in Chicago, 1893, a phototopographic map of a part of the Rocky Mountain Park, comprising a dozen sheets of about sixty square miles each, published on a 1:40000 scale, formed one of the most interesting exhibits of the government of the Dominion of Canada. The topography on each sheet was obtained, on an average, from sixteen stations, giving from seventy to one hundred and twenty panorama views. Six complete panoramas were taken, on an average, from stations situated within the limits of the topography mapped on each sheet and the development of the terrene was controlled by about ten additional camera stations falling outside of the actual sheet margin and furnishing ten additional partial panoramas.

From fifteen to twenty points per square mile were plotted iconometrically, and whenever possible such points were checked by means of vertical and horizontal angles, observed from the several camera stations, for locating (instrumentally) a series of so-called reference points. These fifteen to twenty points form the control per square mile of topography, all intervening

details and topographic features being sketched, after a careful study of the panorama views, in a similar manner as the plane-tabler would sketch such details, under a careful and critical study of the surrounding terrene. The published map, scale 1:40000, shows horizontal contours of one hundred feet vertical interval. The average cost of this survey was about seven dollars and one half per square mile.

The atmospheric conditions of this sparsely settled region, between the 51st and the 52d degree northern latitude, are notoriously unfavorable for executing the field work of the ordinary topographic surveying methods, and the periods of reasonably clear weather at best are of short duration. The field season lasts about three months—July, August, and September—and even during that short period the observers have to contend with fogs, rain, dense smoke caused by forest fires, and snow-storms (in the higher altitudes). These conditions being well known, Capt. Deville's suggestion, to give the phototopographic method a practical trial for the survey of the Rocky Mountain region, was endorsed by the Canadian Government. The good results obtained in the first season showed that the economical and rapid solution of this difficult problem would not have been possible without the aid of photography.

The remarkably good results that were obtained in the phototopographic survey of the Rocky Mountain regions are in a great measure due to the ability of the field observers adapting themselves readily to the new methods, but the credit for the inception of the work, devising new methods, and a compact and serviceable topographic surveying camera suiting the prevailing conditions of the country, and for the general excellence of the results that were obtained, primarily belongs to Capt. E. Deville, Surveyor-General of Dominion Lands and author of an excellent manual on "Photographic Surveying," published by the Canadian Government at Ottawa in 1889. This edition, of about fifty copies, was lithographed in the Survey's office, having been prepared for the use of the Dominion land surveyors

employed under the Department of the Interior for making the phototopographic surveys.

The Rocky Mountain work was suspended when the question arose of making a topographic reconnaissance of S.E. Alaska for the delimitation of the boundary line between S.E. Alaska and British Columbia. This topographic reconnaissance work in Alaska gave the phototopographers of Canada (who for these new duties were placed under the direction of Dr. W. F. King, Alaskan Boundary Commissioner to H. M.) another opportunity to demonstrate the superiority of this method above all other surveying methods for delineating the topography of a country peculiarly rich in climatic and topographic difficulties.

During the summer months (middle of May to end of August) of 1893–94 and to a smaller extent in 1895, this method was used for surveying the topography of S.E. Alaska. Each season's work was plotted in Ottawa in the following winter on 1:80000 scale with horizontal contours of 250 feet vertical interval.

The number of phototopographers prior to 1893 was comparatively small in Canada. Seven of the Dominion land surveyors were given a practical course in phototopography, under J. J. MacArthur, in the suburbs of Ottawa, to familiarize them with the methods and instruments devised by Capt. Deville. In May, 1893, these surveyors were placed in charge of the Canadian phototopographic parties, each chief having assigned him one assistant (also a D. L. S.), from four to five general helpers, or packers, and one cook. The survey being jointly made by both the Canadian and the American Governments, six of the Canadian parties were joined by one U. S. Coast and Geodetic Survey officer with an additional packer for each American.

During the summer season of 1893 these parties experienced an average of but twenty days favorable for carrying on the work in the mountains, and the Canadian expert phototopographer (J. J. MacArthur) occupied about seventeen camera stations during that period. He exposed 108 plates, which controlled an area of about 1150 square miles. The other parties, in charge

of less experienced observers, averaged from,450 to 500 square miles each during the first season.

The season of 1894 proved more favorable for the work in Alaska than the preceding one, both on account of better weather (averaging about forty days suitable for work in the mountains) and because the observers were now more experienced in the rountine and requirements of this class of work. Mr. J. J. MacArthur covered an area of about 1900 square miles, having occupied twenty-four mountain peaks and exposed 275 plates during this season, while the other six parties averaged 1100 square miles each.

These results, however, should not be placed in the same class with the phototopographic survey of the Rocky Mountain Park, as the result aimed at in Alaska was only a topographic reconnaissance, based on a narrow coast triangulation which also extended inland along the more prominent inlets and rivers. This triangulation had been made by the U. S. Coast and Geodetic Survey to control the usual strip of coastal topography and to form the basis for the hydrographic surveys of the navigable waters of S.E. Alaska.

The members of the Coast and Geodetic Survey, who had been attached to Canadian parties in 1893, became familiar with the practical operations and applications of the phototopographic surveying method, and, in 1894, Dr. T. C. Mendenhall, Superintendent Coast and Geodetic Survey and American Boundary Commissioner, had a surveying camera used in conjunction with the plane table for the topographic reconnaissance at the Head of Lynn Canal, Alaska, by which means the area covered with the plane table alone was doubled by the subsequent iconometric plotting in the office from ninety negatives.

The same surveying camera was used by the Coast and Geodetic Survey parties in Alaska in 1895 (Portland Canal) and again in 1897 (Pribilof Islands), under Gen. W. W. Duffield, Superintendent U. S. C. and G. S. and American Boundary Commissioner.

Photography has also been applied recently to surveys made for the solution of questions of irrigation in those regions of the British N.W. Territories where the rainfall is insufficient for agricultural purposes.

Capt. Deville's first edition of his book on photographic surveying having been too limited to supply a general demand he yielded to the pressing demand for an English manual on this subject by revising and reissuing his book. The valuable contents of this work, including the elements of descriptive geometry and perspective, fully justify the expectations that were connected with its appearance.

LITERATURE (ENGLISH).

BRIDGES-LEE. "Phototheodolite," 2d edition. L. Casella, Maker to the Admiralty, Ordnance, etc. London, E.C.

R. STRACHY and G. M. WHIPPLE, Supt. "Cloud Photography conducted under the Meteorological Council at Kew Observatory." Proc. of the Royal Soc. of London, Vol. 49, 1891.

C. W. VERNER. "Notes on Military Topography." Allen. London, 1891.

STANLEY. "Photographic Surveying." San. Eng., 1892, p. 71.

Col. A. LAUSSEDAT. "Topographical Reconnaissances with the Aid of Photography." Phot. Times Almanac, 1895.

B. J. EDWARDS. "Color Screens for Use with Isochromatic Plates and Films." Phot. Times Almanac, 1895.

ALBERT GLEAVES. "Some Scientific Applications of Photography." Phot. Times Almanac, 1895.

OTTO J. KLOTZ. "Experimental Application of the Phototopographical Method of Surveying to the Baird Glacier, Alaska." The University of Chicago Press, 1895.

The Canadian phototopographic methods have been described in the following publications:

Capt. E. DEVILLE. "Photographic Surveying, including the Elements of Descriptive Geometry and Perspective." Ottawa, Government Printing Bureau, 1895.

OTTO J. KLOTZ. "Photogrammetrische Arbeiten in Canada." Zeitschr. des Oester. Ing. u. Archit. Vereins, 1894, pp. 233–234.

Col. A. Laussedat. "Sur le Progrès de l'Art de lever les Plans à l'Aide de la Photographie, en Europe et en Amérique." Comptes rendus de l'Académie des Sciences, 1893.

Col. A. Laussedat. "Reconnaissance faite a l'Aide de la Photographie, pour la Délimitation de la Frontière entre l'Alaska et la Colombie Britanique." Comptes rendus de l'Académie des Sciences. Paris, 1894.

Report of the Superintendent U. S. Coast and Geodetic Survey for 1897, Appendix No. 10, "Phototopographic Methods and Instruments." Washington, D. C.

CHAPTER II.

THE ELEMENTS OF PERSPECTIVE (CENTRAL PROJECTION).

PHOTOGRAMMETRY being the inverse of perspective it may not be out of place here to review, at least in a summary manner, the principal laws of monocular vision, as they are identical in a great measure with the laws which form the foundation of perspective. J. H. Lambert (1728 to 1777) apparently was the first to lay down rules for finding the point of view of a perspective and to determine the dimensions of objects represented in perspective.

I. Visual Seeing.

The eye in order to see an object must receive visual rays from every illuminated point of the object. It is a well-known fact that the retina of the eye receives an inverted image of every sighted object, and yet we all know that objects are *seen* in their natural positions, without requiring a mental transposition of the inverted image into the erect position. The explanation for this may be found in the so-called "law of visible direction," which, according to LeConte, may be stated thus: "The impression on the retina of the eye produced by a ray of light entering the eye is referred from the eye along the ray-line back again into space whence it emanated, and therefore back to its source or proper place."

Every luminous impact which the retina receives by a light ray passing through the nodal point of the lens into the eye is immediately and intuitively referred outward, along the same

path which the entering ray traversed, to the true place which the luminous point occupies in space. In other words, objects sighted as such in space are always the results of "outward projections" from the images on the retina through the nodal point of the eye as center.

II. Central Projection.

If we project from a fixed center—say from the nodal point of the eye—the "visible" parts of an object upon a plane interposed between the eye and the object, the outlines of such projection will produce the same impression on the retina of the eye as the outlines of the natural object, provided, of course, that one eye only was used and at the same time that the rays which emanated from the different points of the pictured object could be made of the same kind (of the same intensity and color) as those coming from the corresponding points of the object itself. The view of such a perspective would then produce sensibly the same impression on the eye of the observer as the object in nature.

Of the different perspectives capable of being represented on a plane surface we are interested here mainly in the so-called monocular or focal and linear or mathematical perspectives, both outgrowths of descriptive geometry and consisting in the application of the rules of projection in general and those of orthogonal projection in particular.

III. Photographic Perspectives.

The iconometrical problem to be solved in phototopography may be stated in the following general terms. From a given perspective (central projection) of a body, projected from a fixed center (point of view, nodal point) upon a (vertical) picture plane, we are to construct the horizontal orthogonal projection of that body.

With reference to Fig. 1, Plate I, we may say the perspective *a, b, c, d, e* in the vertical picture plane *VV* is the central projection of the object *A, B, C, D, E* in space from the nodal point *O* as center or point of view.

Any one object will produce in a given picture plane but one perspective image from the same point as center. A point *B* of the object is pictured but once, in *b*, *b* being that point in the picture plane *VV* where the visual or projecting ray of the point *B* penetrates the plane *VV*.

Of the numerous methods by means of which perspective views may be constructed we shall refer only to those which have reference to iconometric plotting. To elucidate the close connection between the three elements that control or define the central projection or perspective, viz., object, picture plane, and center of projection, with reference to phototopography we may premise, with reference to Fig. 2, Plate I:

A—The picture plane *VV* (photographic plate) is supposed to be vertical.

B—Through the center of projection *O* (eye-point) a horizontal plane *HH* is placed ("horizon plane").

C—A vertical plane is laid through the center *O*, intersecting the picture plane at right angles in the line *vv*; it is the so-called "principal plane."

D—A plane *GG* ("ground plane") is placed parallel with the horizon plane *HH*, but falls below it; the distance *OO* between the two planes is equal to the elevation of the point of view *O* (in the horizon plane) above the datum plane (to which all elevations of the survey are referred). The ground or datum plane in iconometric plotting is identical with the plan and it is represented by the surface of the paper upon which the topographic map is being plotted.

The line of intersection *gg*, Fig. 1, Plate I, of the ground plane *GG* with the picture plane *VV* is known as the "ground line" of the perspective.

The line of intersection *hh*, Fig. 1, Plate I, of the horizon plane *HH* with the picture plane *VV* is termed the "horizon line" of the perspective.

The line of intersection *vv* of the plane ("principal plane") passing through *O* and intersecting the vertical picture plane *VV* at right angles, Fig. 2, Plate I, is called the "principal line" of the perspective.

The intersection O' of the two lines *hh* and *vv*, Fig. 2, Plate I, is the "principal point" of the perspective. It marks the point of penetration in the picture plane of the "principal ray" OO'. The principal ray is drawn from the center *O* (point of view or nodal point) horizontally to intersect the picture plane *VV* at right angles.

The point O_1 where the vertical through the station *O* pierces the ground plane *GG* is termed the "foot of the station."

The length of the principal ray OO', equal to the vertical distance of the point of view *O* from the picture plane, is termed the "distance line."

When the point of view coincides with the second nodal point of a camera-lens this same line, the distance line, is known as the "focal length" of the camera.

The perspective view *a* of a luminous point, *A*, Fig. 2, Pl. I, in the vertical picture plane *VV* is identical with the point of penetration of the visual ray *OA*, passing from the luminous point *A* to the center of projection *O* (point of view or nodal point).

If we have several parallel vertical picture planes *VV*, $V'V'$, $V''V''$, . . . , Fig. 3, Pl. II, the impression produced on the retina of the eye at *O* will remain unchanged, no matter which plane *VV* of the series may be retained in its position while the others are removed.

All planes $V'V'$, $V''V''$, . . ., placed parallel to the picture plane *VV* are termed "front planes" and any line drawn in a front plane will be parallel to the picture plane and is called a "front line." Front planes may be placed either before or behind the picture plane.

The perspective view ab of a line AB is found in the vertical picture plane VV, Fig. 4, Pl. II, by joining the perspectives a and b of its end-points. The perspective ab of a line AB coincides with the trace produced in the vertical picture plane VV by a plane (so-called "visual plane") passing through O and AB; it is the intersection of these two planes.

The perspective a, b, c, d, e of a curve A, B, C, D, E is found by locating the perspectives of a series of its points, a, b, c, d, e, Fig. 1, Pl. I, in the vertical plane VV and drawing a continuous curve through these points. The perspective of a curve may also be obtained by locating the perspectives of a series of tangential lines enveloping the curve. The perspective of a curve a, b, c, d, e is the intersection with the picture plane of that conical visual plane which contains the curve A, B, C, D, E as trace and which has its apex in O.

To draw the perspectives of the superficial planes of bodies, the figures inclosing the same (f.i., the perspective of the pentagon A, B, C, D, E, Fig. 4, Pl. II) are drawn in perspective by constructing the central projections of their perimeters.

The perspectives of parallel lines when produced will intersect each other in one point, the so-called "vanishing point."

The perspectives of all horizontal lines (AB and $A'B'$, Fig. 5, Pl. III) have their vanishing point (D) on the horizon line hh in the picture plane VV.

Lines perpendicular to the picture plane have the principal point of the perspective as vanishing point (in the picture plane).

Horizontal lines intersecting the picture plane under an angle of 45° vanish in the so-called "distance points" on the horizon line, one on either side of the principal point. Their distances from the principal point are equal to the distance line of the perspective.

The so-called upper and lower distance points are the vanishing points for lines falling within the principal plane or that are parallel with it and which intersect the picture plane under an angle of 45°. The distances of these two points from the principal

point are likewise equal to the distance line of the perspective.

Lines parallel with the picture plane, lines in front planes, have no vanishing points in the picture plane. Their perspectives are lines parallel to the original lines.

Vertical lines (are parallel to the picture plane in our case) have no vanishing points and their perspectives are parallel with the principal line vv, Fig. 5, Pl. III.

Horizontal lines when parallel with the picture plane have perspectives that are parallel with the horizon line.

The scale of a front plane is the proportion between the perspective and the original. It is expressed by the ratio between the distances from the station (point of view) to the picture plane, the distance line, and that to the figure's front plane (the plane containing the original figure).

The relationship between object (prism $ABCD–A'B'C'D'$), picture plane (VV), and ground plane (GG) may be shown more clearly with reference to Fig. 5, Pl. III:

O is the station, eye-point, point of view, nodal point, etc. A vertical line passing through O will intersect the ground plane in O_1. The point O_1 is the orthogonal (vertical) projection in horizontal plan of the station O and it is called the "foot of the station" O.

The perspective a_1 of a point A_1', situated in the ground plane GG, is obtained by joining the foot of the station O_1 with the point A_1', erecting a perpendicular to the ground plane in the point of intersection a_1' of O_1A_1' with gg and joining O with A_1'. The intersection of the ray OA_1' with the vertical a_1a_1' just mentioned will be the perspective of the point A_1' of the ground plane GG.

AA_1' being a vertical line in space, its perspective aa_1 will be parallel with the line vv, and, if we draw the ray OA, its intersection a with the line drawn parallel to vv through a_1, previously found, will be the perspective of A.

To find the perspective of a line AB, the perspectives a and b of its terminal points A and B may be located in VV and joined

by a straight line ab. Frequently it will be more convenient, however, to use the intersection T of the line AB with the picture plane VV together with the vanishing point D of the line ab to locate the perspective ab of the line AB. This vanishing point D is the intersection with the picture plane VV of a line drawn through the station O and parallel with the line AB. If AB is horizontal, the line OD will fall within the horizon plane and intersect the horizon line hh at D.

The line TT', which is the trace in the picture plane VV of the plane $ABA'B'$, is termed the "vanishing line" of the plane $ABA'B'$.

CHAPTER III.

PINHOLE PHOTOGRAPHY.

THE photographic camera produces perspectives upon the photographic plate through the chemical action of the light rays upon the sensitized film, and to establish the conditions that are to be fulfilled, in order to regard a photograph as a true perspective, we will first consider the so-called "pinhole pictures," which are produced by a camera of the simplest form.

The pinhole camera consists of a box made entirely light-tight with the exception of a minute hole *O*, Fig. 6, Plate IV, in the front wall of the box. The rear side of the box is removable and may be replaced by either a photographic plate-holder or a ground-glass plate. With such a "camera obscura" photographs may be obtained without a lens or optical apparatus, simply by means of the small round aperture *O* in the thin front wall of the box.

I. Diameter of the Pinhole.

When exercising some care, the pinhole may be made by burning it into a thin blackened cardboard with a needle heated to red heat. The following table gives the diameter in inches that may thus be burnt into the cardboard with needles of different sizes:

Commercial number of sewing-needle........	3	6	8	9
Diameter of burnt hole in inches............	1/26	1/34	1/44	1/49

The best results, however, have been obtained with a round hole carefully drilled into a sheet of copper or brass 0.2 mm. thick. The border of the hole should be perfectly smooth, without "burr," and it should be beveled that the hole forms a truncated cone, the larger circle or base of the cone to face the sensitized plate in the camera-box.

II. Length of Exposure.

The following table, published by F. C. Lambert, gives the corresponding exposures, in minutes, for pinhole-camera exposures, if, with the same plate-brand, identical illumination, same subject, and a lens working at *f*/16, the correct exposure would have been one second.

Distance of Pinhole from the Sensitized Plate Surface, in Inches:	Diameter of Pinhole, in Inches.			
	1/50	1/44	1/35	1/25
6	6	4.5	—	—
8	10	8	5	—
10	16	13	8	—
12	24	18	12	6
14	32	24	15	8
16	40	32	20	10
18	—	41	26	13
20	—	—	32	16
24	—	—	—	24

This table plainly indicates that there is little danger of overexposing a plate in the pinhole camera, particularly as these exposures are not strictly limited to the time given in the table; they depend greatly on the general character of the plate, on the developer, and on the general conditions of illumination during the exposure, thus giving the operator a wide range regarding the time limit of the exposure.

III. Focal Lengths of Pinhole Cameras.

The depth of focus is practically unlimited, as shown in the preceding table of F. C. Lambert. Still, there will always be a certain distance between image plane and pinhole that will give the best result for a given aperture, and Capt. Colson recommends the following focal distances for a set of apertures of four different sizes:

Diameter of pinhole in millimeters	0.3	0.4	0.5	0.6
The best definition is at a focal length, in centimeters	11	20	30	44

Using the focal length corresponding to the size of aperture, as given in the above table, the time of exposure for a plate in the pinhole camera, compared with the exposure required when using a lens under identical conditions and with a medium stop, may be generally accepted to be:

25	50	100	200	times longer for a diameter of hole of:
0.3	0.4	0.5	0.6	mm.

The size of a pictured object, when photographed in a pinhole camera, is proportional to the ratio between the distance of the object from the camera and the distance from the pinhole to the sensitized film surface.

IV. Determination of the Values of the Pinhole-camera Constants.

It will be a simple matter to determine the values of the constants of a pinhole camera that are required to be known for making iconometric constructions.

If the angles of the box are exactly 90°, if the aperture is in the point of intersection of the diagonals of the camera front, and if means are provided for setting the camera level (for exposing the plate in vertical plane), the two lines joining the opposite

middles of the four sides which compose the rear frame of the box will represent the horizon line (HH) and the principal line (VV) of the photographic perspective. The intersection (P) of these two lines will be the principal point and the distance (OP) between the aperture and the sensitive film surface will be the constant focal length or the distance line of the photographic perspective a, b, c, Fig. 6, Plate IV.

By referring to Fig. 6, Plate IV, it will readily be seen that the rays of an object A, B, C, after passing through the aperture O, produce an inverted image a, b, c on the photographic plate. The image obtained in a pinhole camera originates in the same way as a perspective is drawn, with the exception that the picture plane $V'V'$ is not interposed between the eye-point O and the original A, B, C, but is here placed behind the eye-point, at a distance PO equal to OP', producing an inverted and reduced image a, b, c of the original A, B, C.

By introducing the "negative" with the image a, b, c between the eye-point O and the original A, B, C at $V'V'$, Fig. 6, Plate IV, and at a distance from O equal $OP'=OP$ (in- and reverted), it would become a "positive." P' being in the prolongation of the distance line OP and $V'V'$ intersecting the line OP' at right angles, the line hh of the "positive" will be horizontal and vv vertical. The point a will again be in the point of intersection of the light-ray OA, the point b in the intersection of the light-ray OB, and the point c in the intersection of the light-ray OC with the plane of the positive $V'V'$. A positive copy of a negative will be as true a perspective of the original as the negative. Negatives, however, may be used for obtaining any measurements that may be required from the perspective for the iconometric plotting. Measurements are often preferably made on the negatives, as the production of the positives without distortion requires considerable care and experience, the amount of distortion depending greatly on the character of the material on which the positives are made.

The data given in this chapter may prove useful when a

pinhole camera is selected for phototopographic or photogrammetric experimental studies in case of an emergency, or when the cost of the apparatus must be considered, the pinhole camera being recommendable chiefly on account of its cheapness and simplicity.

CHAPTER IV.

THE FUNDAMENTAL PRINCIPLES OF ICONOMETRIC MAP-PLOTTING ("ICONOMETRY").

UNDER "iconometry" we understand the measuring of dimensions of objects from their perspective views ("Bildmesskunst"). It refers to the plotting of terrene forms directly on the plotting-sheet from the photographs of the landscape.

If a photographic perspective of an object, the focal length ("distance line"), the second nodal point ("principal point") of the camera-lens, and the horizon line of the perspective are given—if the point of view and the central projection of an object are given—these data will be insufficient for the determination of the object with reference to position and size.

If, however, *two* such perspectives of the same object, obtained from two suitably located stations, be given, the dimensions of the object and its position with reference to the two stations may be determined iconometrically, very much in a manner analogous to that in which a point is located (by intersection or by the so-called radial method) on the plane-table sheet by being observed upon from two known plane-table stations.

I. Orienting the Picture—Traces on the Plotting-sheet.

The positions of two camera stations A and A', their linear horizontal distance AA' and two photographs, exposed in vertical plane, one from each station, may be given. Each picture may, furthermore, contain the image t of the same object T and the image a of the other camera station, Fig. 7, Plate IV.

After the base line AA' has been laid down in reduced scale A_1A_1', Fig. 7, Plate IV, and the pictures MN and $M'N'$ are brought into the same relative positions with reference to the line A_1A_1', which they had with reference to the base line AA' in the field at the time of their exposure, the position T of the point pictured as t and t' on the respective pictures MN and $M'N'$ may be located (with reference to the line A_1A_1') by drawing the radials A_1t and $A_1't'$, when their point of intersection will fix the relative position of T with reference to A_1 and A_1'.

The position of T on the map, plotted to scale with reference to the reduced base line or with reference to the plotted stations A_1 and A_1', would be found by projecting the point of intersection T into the plotting or ground plane.

A topographic map being the orthogonal projection of the terrene forms into horizontal plan, the horizontal projections into the plotting-plane of the rays A_1t, A_1a_1', $A_1't'$, and $A_1'a$ are used to locate the plotted positions of pictured points t and a and the horizontal projections of the picture planes (which now become "picture traces") are utilized in this connection, instead of actually using the pictures in the iconometric plotting as was indicated in the diagram of Fig. 7, Plate IV.

In order, therefore, to plot the horizontal projection T_1 of a pictured point t with reference to the plotted base line A_1A_1', it will become necessary to ascertain the correct positions of the picture traces with reference to A_1 and A_1'—it will become necessary to "orient" the picture traces hh and $h'h'$, Fig. 8, Plate V.

This orientation of the picture traces forms a very important part in iconometric plotting, as the subsequent fixing of locations of pictured points is accomplished mainly by bringing the horizontal projections of their radials (lines of horizontal directions drawn from the different stations to identical terrene points) to intersect. Any error in the orientation of the picture trace produces corresponding errors in the plotted positions of pictured points.

A. Iconometric Plotting when using a Surveying Camera only.

A base line measured in the field may have been plotted to scale, A_1A_1', Fig. 8, Plate V, and two pictures, MN and $M'N'$, Fig. 9, Plate V, may have been obtained from the camera stations A and A' respectively by means of a surveying camera. The focal lengths of the pictures $=f$ and f' respectively, the positions of the principal points P and P' and the horizon lines HH and $H'H'$ may be known. It is desired to locate T_1 with reference to the plotted base line A_1A_1'.

We have $A_1P_1=f$; $A_1'P_1'=f'$; the length of the base $=A_1A_1'$, and the abscissæ $t_1P=t_1P_1$, $t_1'P'=t_1'P_1'$, $Pa_1'=P_1a_1'$, $P'a_1=P_1'a_1$, Figs. 8 and 9, Plate V.

The distances A_1a_1', and $A_1'a_1$, Fig. 8, may be found graphically by constructing the right-angle triangles $A_1P_1a_1'$ and $A_1'P_1'a_1$, or they may be computed from

$$
{}_1a_1'=\sqrt{(A_1P_1)^2+(P_1a_1')^2},
$$
$$
A_1'a_1=\sqrt{(A_1'P_1')^2+(P_1'a_1)^2}.
$$

These distances are laid off upon A_1A_1' from A_1 and from A_1' respectively a semicircle is described over each length, A_1a_1' and $A_1'a_1$, and two circles are drawn about A_1 and A_1' with f and f' respectively as radii. The intersections of these two pairs of circles will locate the horizontal projections P_1 and P_1' of the principal points P and P' on the two picture traces hh and $h'h'$, the latter being represented by the tangents P_1a_1' and $P_1'a_1$.

B. Plotting the Picture-trace when using a Camera or Phototheodolite.

In this case the angles α and α', Fig. 8, Plate V, may be measured directly in the field and plotted on the base line A_1A_1', α at A_1 and α' at A_1'. We lay off the distances

$$
A_1a_1'=\sqrt{f^2+(P'a_1')^2}
$$

and

$$
A_1'a_1=\sqrt{(f')^2+(P_1'a_1)^2}
$$

(found by construction or computation) and describe circles about A_1 and A_1' with f and f' respectively as radii. The tangents drawn from a_1' and a_1 to these circles will locate P_1 and P_1' respectively when P_1t_1 should equal $t_1P=x$, measured on the picture MN, and $P_1't_1'=P't_1'=x'$ on $M'N'$.

When using a phototheodolite a well-defined point T may be bisected with the principal lines VV and $V'V'$, Fig. 9, Plate V, from the two stations A and A_1, in which case these angles of orientation are laid off upon the base line at A_1 and at A_1' respectively, and the distances f and f' are laid off on the lines A_1T_1 and $A_1'T_1$ respectively ($=A_1P_1$ and $=A_1'P_1'$), when the perpendiculars to A_1P_1 in P_1 and to $A_1'P_1'$ in P_1' will represent the picture traces hh and $h'h'$ in correct orientation with reference to A_1, A_1', and T_1.

When the pictures of several triangulation points B, C, and D and the base line are given, the orientation of the picture traces hh and $h'h'$ upon the plotting-sheet may be accomplished as follows:

The radials A_1B_1, A_1C_1, A_1D_1 . . . , as well as the radials $A_1'B_1$, $A_1'C_1$, $A_1'D_1$ . . . , are drawn upon the iconometric plotting-sheet, the points B_1, C_1, D_1 . . . being already plotted on the same. The points b_1, c_1, P, d_1, and a_1' are then transferred from the horizon line OO_1 of the photographic perspective MN, Fig. 11, Plate VI, upon the perfectly straight edge of a strip of paper, which now is placed upon the radials converging to A_1, as a center, Fig. 10, Plate V, and moved about until

b_1	falls	upon	the	radial	line	A_1B_1,
c_1	"	"	"	"	"	A_1C_1,
d_1	"	"	"	"	"	A_1D_1,
a_1'	"	"	"	base	"	A_1A_1'.

The line A_1P_1 should then be perpendicular to the straight edge hh of the paper strip, Fig. 10, Plate V, and the line hh, drawn along the paper strip's edge on the plotting-sheet will

represent the oriented picture trace of MN; A_1P_1 will be the distance line and P_1 the horizontal projection of the principal point P.

The same having been done regarding the point A_1', its picture $M'N'$ and the paper strip O_1O_1' (Fig. 11, Plate VI), both picture traces hh and $h'h'$ will have been oriented. The plotted positions of any other pictured points that may be identified on *both* pictures MN and $M'N'$ may be similarly located by plotting their abscissæ (measured on the horizon lines OO_1 and $O'O_1'$) upon the picture traces hh and $h'h'$ (Fig. 10, Plate V) on the proper sides of the principal points P_1 and P_1'.

Lines drawn from the station points A_1A_1' through such corresponding points, transferred to their respective picture traces, will locate the relative positions of such points on the plotting-sheet by their points of intersection.

II. Arithmetical Determination of the Principal and of the Horizon Line on the Photographic Perspectives.

In the preceding paragraphs it has been assumed that the photographic perspectives were already provided with the principal and the horizon lines. Such, in point of fact, would be the case with an *adjusted* surveying camera or phototheodolite. If the instrument is out of adjustment or if an ordinary camera be used (one provided with a device for maintaining the image plane in a vertical position during the exposure of the plate), the correct positions of the principal and horizon lines, as well as the length of the distance line, must be ascertained. In phototopographic work this may be accomplished in various ways.

A. Determination of the Principal Point and Distance Line of the Photographic Perspective.

A plumb line suspended in front of the camera in such a way that the line vv, Fig. 12, Plate VI, may be photographed

upon the negative will serve to establish the direction of the principal line on the trial plate. This negative may, furthermore, contain the images *a*, *b*, *c* . . . of three or more points *A*, *B*, *C*, . . . of known positions and elevations. A line *hh* is drawn at right angles to the pictured plumb line *vv* on the photographic perspective and a strip of paper is placed with its straight edge along this line. The images *a*, *b*, *c* . . . of the known points *A*, *B*, *C* . . . are projected upon the paper straight edge, held in position at *hh*, by drawing parallels to *vv* through these pictured points.

After the radials from the plotted station S_1, Fig. 12, Plate VI, have been drawn through the plotted points A_1, B_1, C_1 . . . the paper strip is adjusted upon those radials in such manner that the image projections a_1, b_1, c_1 . . . (previously marked on the strip) will fall upon their corresponding radials; a line drawn along the edge of the paper strip while in this position will represent the oriented picture trace, as indicated by the line h_1h_1.

If we now draw a perpendicular line (S_1P_1) to h_1h_1 from the plotted station S_1, the point P_1 will be the horizontal projection of the principal point *P* and $S_1P_1 = f$ will be the distance line for the perspective *MN*.

Should the positions of the points *A*, *B*, *C* . . . with reference to the station *S* be not known, it will become necessary to observe the horizontal angles *ASB*, *BSC*, *CSD* . . . instrumentally from the station *S* and plot them in their proper order upon a sheet of paper ($A_1S_1B_1$, $B_1S_1C_1$ . . .) and adjust the paper strip *hh* upon these radials in the same manner as just described.

B. Determination of the Position of the Horizon Line on the Perspective.

When the elevations *AA'*, *BB'*, *CC'* . . . (Fig. 13, Plate VII) of the points *A*, *B*, *C* . . . above the horizon plane *SOO'* of the

station S are known, the position of the horizon line OO' on the perspective MN may be found by computing the ordinates aa', bb', cc' ... from the equations:

$$aa':AA'=Sa':SA',$$
$$bb':BB'=Sb':SB',$$
$$\begin{matrix} . & . & . & . \\ . & . & . & . \\ . & . & . & . \end{matrix}$$

whence

$$aa'=\frac{Sa'\times AA'}{SA'}=y,$$
$$bb'=\frac{Sb'\times BB'}{SB'}=y_1$$
$$\begin{matrix} . & . & . & . \\ . & . & . & . \\ . & . & . & . \end{matrix}$$

The distances Sa', Sb', Sc' ... are taken from the plotting-sheet. The horizontal distances SA', SB', SC' ... and the differences in elevations AA', BB', CC' ... are known.

For example, the difference in elevation between A and $A'=100$ m., the distance of A' from the station $S=1000$ m., and the distance Sa', measured on the plotting-sheet, $=0.05$ m., then we will have

$$aa'=y=\frac{0.05\times 100}{1000}=0.005 \text{ m.}$$

The horizon line OO' on the negative will be 5 mm. vertically below the pictured point a (measured in a direction parallel with the pictured plumb line vv). A line OO' drawn through a' at right angles with the pictured plumb line vv will locate the horizon line. The computed ordinates $bb'=y_1$, $cc'=y_2$ ... of the other pictured points b, c ... will serve to check the position of the horizon line OO'; it should be tangent to the arcs described with aa', bb', cc' ... about a, b, c ... respectively as centers.

III. Graphic Method for Determining the Positions of the Principal and Horizon Lines on the Perspectives.

The following method for orienting the picture trace, published by Prof. F. Schiffner, in 1887, and mentioned by Prof. Steiner, leads to the same result graphically as the preceding one does arithmetically.

The horizontal projections A_1, B_1, C_1, and S_1 of three points A, B, C, and station S, Fig. 14, Plate VII, may be given. From S_1, as center, radials are drawn through A_1, B_1, and C_1. Through a point a on the radial S_1A_1 a parallel to S_1C_1 is drawn and the distance $a'b'$—taken from the negative MN, not shown in the figure—is laid off from $a = ab_1'$ upon this parallel line, while the distance $b'c'$ is laid off upon the same line from $b_1' = b_1'c_1'$.

Parallels to the radial S_1A_1 are then drawn through the points b_1' and c_1' and produced to intersect with the radials S_1B_1 and S_1C_1. The line $h'h'$ connecting these two points of intersection will be parallel with the direction of the picture trace.

The same distances $a'b'$ and $b'c'$—taken from the negative—are laid off upon this line $h'h'$ from $a_2 = a_2b_2$ and from $b_2 = b_2c_2$ respectively. The parallels to the radial S_1A_1, drawn through these points b_2 and c_2, are brought to intersections with the radials S_1B_1 and S_1C_1, when the line hh, passing through these intersections b' and c', will represent the picture trace, oriented with reference to S_1, A_1, B_1, and C_1.

The distance S_1P_1 of S_1 from hh represents the distance line (focal length) of the picture MN, and the point P_1 will be the horizontal projection of the principal point of the perspective.

After having transferred P_1 (with reference to a', b', and c') to the perspective MN by means of a strip of paper, a parallel to the pictured plumb line vv drawn through the point P_1 will locate the principal line upon the negative.

III. The "Five-point Problem" (by Prof. F. Steiner), or Locating the Plotted Position of the Camera Station by Means of the Perspective when Five Triangulation Points are Pictured on the Same Photographic Perspective.

In the methods considered until now it had been assumed that the position of the camera station S_1 on the plotting-sheet was known with reference to the plotted triangulation points A_1, B_1, C_1 . . . .

In case the panorama pictures have been taken from a camera station S_1 of unknown position and a series of known points are pictured upon the panorama views, both the position of the camera station may be found (with reference to the positions of the surrounding points of known positions) and the picture trace may be oriented by means of Prof. F. Steiner's "five-point problem," if one of the panorama views contains the pictures of five or more points of known positions.

A. Determination of the Principal Point and Distance Line.

A panorama view MN may contain the images a, b, c, d, e of the triangulation points A, B, C, D, E, already plotted on the working-plan, and also the picture of a suspended plumb line or other vertical (or horizontal) line sufficiently long to be used for drawing parallel lines to the principal (or horizon) line.

The points a, b, c, d, and e of the negative MN are projected upon the straight edge of a strip of paper $= a_1$, b_1, c_1, d_1, and e_1. Radials are now drawn from one—A_1, Fig. 15, Plate VIII—of the five plotted points as center to the other four points, B_1, C_1, D_1, and E_1. The paper strip is then placed over the radials A_1B_1, A_1D_1, and A_1E_1, that b_1 falls upon A_1B_1, d_1 upon A_1D_1, and e_1 upon A_1E_1, when the strip will have the position a_1, b_1, c_1, d_1, e_1. The line drawn through A_1 and a_1 (the latter having been transferred to the sheet by means of the paper strip)

will be tangent in A to the ellipse E_1 (which passes through A_1, B_1, D_1, and E_1 and through the plotted station S_1).

The paper strip is now placed over the radials A_1B_1, A_1C_1, and A_1D_1, that b_1 falls upon A_1B_1, c_1 upon A_1C_1, and d_1 upon A_1D_1, when the strip will have the position indicated by a_2, b_2, c_2, d_2, e_2, and the line A_1a_2 will be the tangent in A_1 to the ellipse E_2 (passing through the points A_1, B_1, C_1, D_1, and the plotted station point S_1).

The plotted position of the station point S_1 with reference to the five plotted points A_1, B_1, C_1, D_1, and E_1 will be at the fourth point of intersection S_1 of the two ellipses E_1 and E_2.

After drawing the radials S_1A_1, S_1B_1, S_1C_1, S_1D_1, and S_1E_1 the paper strip is placed over these radials in such manner that a_1 falls upon S_1A_1, b_1 upon S_1B_1, . . . and e_1 upon S_1E_1, in the position indicated by a, b, c, d, $e=HH$, when HH will be the plotted picture trace.

The perpendicular upon HH passing through $S_1=S_1P_1$ represents the distance line and P_1 is the principal point of the negative projected into the horizontal plan, which, in order to locate the principal line, may now be transferred to the perspective by means of the paper strip in the manner already described.

B. Simplified Construction for Locating the Plotted Position of the Camera Station by Means of the "Five-point Problem."

The method just described being rather complicated, Prof. Schiffner recommends the following construction, Fig. 16, Plate IX, in which the drawing of the two ellipses E_1 and E_2 is avoided:

The plotted positions of the same five points A, B, C, D, and E, together with a negative containing the images a, b, c, d, and e, of these points may be given. It is desired to find the fourth point of intersection S_1 of the two ellipses E_1 and E_2 without actually drawing their perimeters.

The two tangents b_3B_1 and b_4B_1 to the ellipses E_1 and E_2 in B_1 are located in precisely the same manner as the two tangents a_1A_1 and a_2A_1 for the point A_1 were found in Fig. 15, Plate VIII. The intersections R_1 and R_2 of the tangent pairs a_1A_1, b_3B_1, and a_2A_1, b_4B_1, Fig. 16, Plate IX (belonging respectively to the ellipses E_1 and E_2), are situated on a line QX, forming one side of the polar triangle QXT, common to both ellipses. This line $R_1R_2=QX$ intersects the diagonal A_1D_1 in X and the quadrilateral side B_1D_1 in the point Q. The lines drawn through Q from A_1 and through X from B_1 will intersect each other in the fourth point of intersection S_1 of the two ellipses.

This method may also appear rather complicated in view of the many lines that have to be drawn before the picture trace HH and the position of the camera station may be plotted.

C. *Application of the "Five-point Problem" to the Special Case, where the Five Points range themselves into a Triangle on the Working-sheet.*

The application of the five-point problem becomes very much simplified when the five points A, B, C, D, and E form a triangle of which two sides A_1C_1 and C_1E_1, Fig. 17, Plate X, contain three points each.

If we place the strip of paper upon the radials, drawn from A_1, that e_1 falls upon A_1E_1, d_1 upon A_1D_1, and c_1 upon A_1C_1, it will have the position indicated by a_2, b_2, c_2, d_2, e_2, and the first ellipse will resolve into the lines C_1E_1 and A_1a_2. If we now place the paper strip a_1, b_1, c_1, d_1, e_1 upon the radials drawn from E_1 to A_1, to B_1 and to C_1, that a_1 falls upon E_1A_1, b_1 upon E_1B_1, and c_1 upon E_1C_1, it will assume the position a_1, b_1, c_1, d_1, e_1, and the second ellipse will resolve into the lines A_1C_1 and E_1e_1.

The intersection S_1, of the two lines A_1a_2 and E_1e_1, locates the position of the plotted station point S_1 with reference to the five given points A_1, B_1, C_1, D_1, E_1. By placing the paper strip upon the radials S_1A_1, S_1B_1, S_1C_1, S_1D_1, and S_1E_1 in

such manner that a_1 falls upon $S_1A_1b_1$, upon S_1B_1, c_1 upon $S_1C_1 \dots$, its edge HH will locate the picture trace, P_1' will be the horizontal projection of the principal point P, and S_1P_1 will be the distance line.

D. To find the Elevation of the Camera Horizon for a Station that has been located by means of the "Five-point Problem."

To ascertain the elevation of the station S, plotted after one of the preceding methods, it will be necessary to know the elevations of at least two of the five given points. The elevation of the station horizon SOO', Fig. 13, Plate VII, above the datum or ground plane $S'O_1O_1'$, may be designated by X, H and H_1 may be the elevations of A and B respectively, both supposed to be known. The ordinates of the pictured points a and b are $aa'=y$ and $bb'=y$.

From the relation $S'a_1':S'A_1'=aa':AA'$

or
$$Sa':SA'=y:(H-X)$$

we find
$$y=\frac{Sa'}{SA'}(H-X),$$

and
$$y_1=\frac{Sb'}{SB'}(H_1-X).$$

As the difference between y and y_1 may be found by direct measurements made on the negative, $y-y_1=m$ will be known and the value for X may be computed from the equation

$$y-y_1=m=(H-X)\frac{Sa'}{SA'}-(H_1-X)\frac{Sb'}{SB'},$$

since the measures for Sa', SA', Sb', and SB' may be obtained from the plotting-sheet, measured in the scale of the map.

The above equation may be written in the general form:

$$m=\frac{H-X}{n}-\frac{H-X}{p}, \quad \text{where} \quad \frac{1}{n}=\frac{Sa'}{SA'} \quad \text{and} \quad \frac{1}{p}=\frac{Sb'}{SB'};$$

hence

$$X=\frac{m\cdot n\cdot p-H\cdot p-H_1\cdot n}{n-p}.$$

By substitution of this value in the equations

$$y=\frac{H-X}{n} \quad \text{and} \quad y_1=\frac{H_1-X}{p},$$

the numerical values for the ordinates y and y_1 (governing the position of the horizon line) may be found.

V. The "Three-point Problem."

If the triangulation points are not sufficiently close together that five or more points may be pictured on one photographic perspective, and if stations are occupied with the camera that are not directly connected with the trigonometric system, it will become necessary to employ other means than those heretofore considered for locating the position of such detached camera stations with reference to the triangulation system.

To connect detached camera stations with the triangulation by observations made at the camera station, at least three triangulation points should be visible from such station. When the camera party is in advance of the triangulation party many camera stations will be located by the triangulation party by observing upon a signal left at the camera station, if such signal be visible from two or more triangulation stations (the camera station will be a "concluded point" of the triangulation system).

The determination of the position of a detached camera station by observing upon three fixed and known points (provided with signals) is generally known as the "three-point problem" (station-plotting, station-pointing, etc.), or "Pothenot's method," although Snellius was probably the first to use this method (in his trigonometric surveys in the Netherlands in the second decade of the seventeenth century).

A. Mechanical Solution of the "Three-point Problem" (using a Three-arm Protractor or Station-pointer).

The simplest solution of the three-point problem is purely mechanical in application. The two observed angles M and N are laid off upon a three-arm protractor ("station-pointer") or upon a sheet of tracing-paper, and the three arms or lines S_1A_1, S_1B_1, and S_1C_1, Fig. 18, Plate X, are placed over the three fixed and plotted points A_1, B_1, and C_1 in such manner that the three lines of direction S_1A_1, S_1B_1, S_1C_1 pass through their respective points A_1, B_1, and C_1, the point S being transferred to the working-sheet while holding the two horizontal angles M and N in unchanged position.

B. Graphic Solution of the "Three-point Problem."

1. Using the So-called "Two-circle Method."

Theoretically the best graphic method is probably that by which the position of the fourth, or station, point is located at the intersection of two circles, one passing through A_1 and B_1 and having over A_1B_1, as chord, the angles of circumference $=A_1S_1B_1=M$, Fig. 18, Plate X, the second circle passing through B_1 and C_1 and having over the chord B_1C_1 the angles of circumference equal to $B_1S_1C_1=N$.

From the plotted triangle side A_1B_1 we lay off at A_1 and B_1 the angles $B_1A_1C_1$ and $A_1B_1C_1$, each equal to

$$\frac{180-2(A_1S_1B_1)}{2}=90^\circ-A_1S_1B_1=90-M,$$

and about the point C_1, thus obtained, we describe a circle $A_1B_1S_1$ with the radius $=C_1A_1=C_1B_1$. The observed angle $A_1S_1B_1=M$ will then be an angle of circumference over A_1B_1, and the point S_1 will be located somewhere on the arc over A_1B_1.

By means of the angle $B_1S_1C=N$ another circle B_1CS_1 is described over the triangle side B_1C, in a similar manner, about the point C_2 as center, having $C_2B_1=C_2C$ as radius. The observed second angle $B_1S_1C=N$ will be an angle of circumference over the chord B_1C and the point S_1 will be on the arc over B_1C, hence its true position is at the (second) point of intersection S_1 of the two circles.

2. Using the Method of Bohnenberger and Bessel.

The following method, by Bohnenberger and Bessel, is readily applied and simple in construction. If we describe a circle through two of the given points, through A_1 and B_1, Fig. 19, Plate XI, and through the station S_1, the angles designated by M and those designated by N in the figure will be respectively equal, being angles of circumference over the same arcs A_1D_1 and D_1C_1 respectively.

Hence if we lay off the observed horizontal angle N on A_1C_1 at A_1, and the other observed horizontal angle M on the line A_1C_1 at C_1, the point of intersection D_1 of their convergent sides C_1D_1 and A_1D_1 will fall upon the line connecting the third plotted triangulation point B_1 with the station point S_1.

After having thus determined the direction of the line B_1D_1 or B_1S_1 the position of the point sought may be found as follows:

At any point x on the produced line B_1D_1 the observed angles M and N are laid off to either side of B_1D_1, in the sense in which

they were observed at S. Lines A_1S_1 and C_1S_1, drawn through A_1 and C_1, parallel to xy and xz respectively, will locate the plotted position of the station point S_1 (upon D_1B_1) with reference to the three plotted points A_1, B_1, and C_1.

This solution is recommended only when B_1D_1 is sufficiently long (in Fig. 19, Plate XI, it evidently is too short) to assure a correct prolongation toward S_1.

The picture trace HH, containing the horizontal projections of the pictured points a, b, c, may now be oriented in the known manner by adjusting the paper strip, having the three points a_1, b_1, and c_1 marked on its edge, over the radials S_1A_1, S_1B_1, and S_1C_1 to bring a_1 on S_1A_1, b_1 on S_1B_1, and c_1 on S_1C_1.

VI. The Orientation of Picture Traces, Based on Instrumental Measurements Made in the Field.

When no points of the area to be mapped phototopographically are known, the elements (horizon line, principal point, and distance line) of the photographic perspectives can no longer be determined from the photographs alone. Instrumental observations will have to be made at the camera stations in the field to supply the data needed for their determination. This method, among others, having been adopted by Capt. Deville, will be described in the chapter giving the description of the Canadian surveying-camera.

VII. Relations between Two Perspectives of the Same Object, Viewed from Different Stations.

(Prof. Guido Hauck's Method.)

A more general application of photogrammetric methods dates from the publication of Prof. G. Hauck's investigations and results regarding the relationship between trilinear systems of different planes (Guido Hauck, "Theorie der trilinearen

Verwandtschaft ebener Systeme," Journal fuer reine und angewandte Mathematik, L. Kronecker und Weierstrass, Bd. 95, 1883). In this publication Prof. Hauck discusses the relationship between the projections of the same object upon three different planes. The practical value of his theoretical deductions was fully established and tested practically by the students of the Royal Technical High School of Berlin who attended Prof. Hauck's lectures and exercises connected with the course in descriptive geometry in 1882.

In the discussion of the relation between three perspectives of the same object Prof. Hauck refers to some properties of decided value in iconometric plotting. The principal law (as deduced by Prof. Hauck) with reference to phototopography may be stated as follows:

If an object be projected from three different points as centers upon three different planes that may have any position in space, one of these projections (perspectives) can be evolved from the other two by means of graphic construction. Or, expressed in terms more suited to our case, if an object has been photographed on three plates exposed from different stations, any one of these photographic perspectives may be evolved graphically from the remaining two. A topographic map (the orthogonal projection of the terrene) may be regarded as a central projection or perspective in a horizontal plane, having its center of projection (point of view) at infinite distance, and we may state Prof. Hauck's law as follows:

From two photographs MN and $M'N'$ of the same terrene, taken from different stations S and S', the orthogonal horizontal projection of the terrene may be obtained graphically by means of rays emanating from the so-called "kernel points" ("Kernpunkte") as centers.

The line of intersection of the two photographs (the two planes of projection or perspective planes) MN and $M'N'$, Fig. 20, Plate XI, will be the "perspective axis."

To better illustrate the connection between two different

photographs we will first refer to the simple case of two vertical perspective planes or photographs MN and $M'N'$, Fig. 20, Plate XI.

A. "Kernel Points" and "Kernel Planes."

Let S and S' represent the two camera stations (centers of projection or points of view for the two vertical photographic perspectives MN and $M'N'$), let s' be the picture in MN of S', and s be the picture of S in $M'N'$, then these two pictured stations s and s' will be so-called "kernel points" ("Kernpunkte").

The two picture planes MN and $M'N'$ intersect each other in the line $I\Omega$, the so-called "perspective axis."

Planes passing through the line SS' (base line) will contain the "kernel points" s and s'; they are termed "kernel planes" ("Kernebenen").

A kernel plane M_2N_2, laid through any point A, pictured as a and a', will intersect the first picture plane MN in the line as' and the second picture plane $M'N'$ in the line sa'. These lines of intersection (as' and $a's$) will intersect the "perspective axis" $I\Omega$ in the same point Ω; they will contain the pictures a and a' of the point A, and they will pass through the picture s and s' of the two camera stations S and S'.

The lines $S'A$, SA, SS', as', and $a's$ fall within the "kernel plane" M_2N_2. All lines as' for all points pictured in MN will pass through the pictured station point s' (image of the second camera station S'), and all lines as for the picture plane $M'N'$ will pass through the pictured point s of the camera station S. Furthermore, all pairs of lines (as' and $a's$) joining the perspectives (a and a') of identical points (A) with their corresponding pictured station points ("kernel points" s' and s) will intersect the "perspective axis" ($I\Omega$) of the two pcture planes (MN and $M'N'$) in identical points (Ω).

From two photographs of the same object which also contain the pictures of the two reciprocal stations peculiar advan-

tages may be gained for the iconometric plotting, inasmuch as such pictured stations s' and s will be "kernel points."

The perspective axis of the picture planes may also play an important part in iconometric plotting, not only for pictures exposed in vertical planes, but even more so for inclined picture planes.

If two photographs MN and $M'N'$ are given (in Fig. 21, Plate XII, their traces are represented by the lines HH and $H'H'$) representing the same object, viewed from the two stations S and S' without containing the pictures of the stations, the positions of the pictures s and s' of the corresponding camera stations S and S' may be located upon the picture planes (outside of the actual field of the photograph) by construction.

The horizontal projections s_1 and s_1' of the "kernel points" s and s' are identical with the points of intersection of the plotted base line SS' and the picture traces HH and $H'H'$, Fig. 21, Plate XII. Hence, if we revolve the picture planes MN and $M'N'$ about their ground lines, until they coincide with the ground plane, the line $I\Omega$, common to both picture planes (the "perspective axis"), will be represented by the two lines $i(I)$, and the "kernel points" s and s' of the revolved planes MN and MN will fall upon the lines $s_1(S_1)$ and $s_1'(S_1')$ respectively (these lines are perpendiculars upon the picture traces in the horizontal projections s_1 and s_1' of the kernel points s and s').

To find the lengths $s_1(S_1)$ and s_1' (S_1') (the ordinates of the "kernel points" in the picture planes above the ground lines) we erect perpendiculars to the base line in S and S' with lengths equal to the elevations of the camera stations above the ground plane $= S(S)$ and $S'(S')$ respectively.

The line $(S)(S')$—the vertical plane passing through the base line S has been revolved about the horizontal projection of the base line into the ground plane to coincide with the latter—will intersect the lines $s_1(S_1'')$ and $s_1'(S_{11}')$—they are perpendiculars to SS' in the "kernel points" s and s—and the lengths $s_1(S_1'')$ and $s_1'(S_{11}')$ will be equal to the ordinates of the "ker-

nel points" s and s' above the ground lines of MN and $M'N'$.

The "kernel points" s and s', Fig. 20, Plate XI, may be located after this manner in the picture planes of any two photographs, provided such picture planes are not parallel (or even nearly so) with the base line SS'.

B. Use of the "Perspective Axis" (Line of Intersection) of two Picture Planes that show identical Objects viewed from different Stations.

If a series of characteristic points of the terrene, pictured in a vertical plane MN, Fig. 22, Plate XII, are connected with the "kernel point" s by straight lines, these will, when produced, intersect the perspective axis $I\Omega$, and if the images of the corresponding identical points in the vertical picture plane $M'N'$ are joined with the "kernel point" s', and if these lines are likewise produced to intersect the "perspective axis" $I\Omega$, the points of intersection of $I\Omega$ with the first group of lines (belonging to MN) will be identical with the points of intersection of $I\Omega$ with the second group of lines (belonging to $M'N'$).

If we now provide the "perspective axis" with a scale of equal parts (having the zero or origin of graduation in the ground plane), lines drawn through the "kernel points" and through corresponding images of identical points in both picture planes will intersect identical points of this scale.

The length $O'O$, Fig. 22, Plate XII, intercepted on the scale of the "perspective axis" by the two horizon lines of the picture planes MN and $M'N'$ represents the difference in elevation of the two camera stations S and S'. The scale $I\Omega$ may be drawn on both pictures to show on both lines $i(I)$, Fig. 21, Plate XII, after the pictures have been separated. Frequently the picture itself will not be sufficiently extended to contain the line $I\Omega$, in which case such a scale may still be used by placing it upon a line XX'', in MN, and upon zz'', in $M'N'$, some dis-

tance from but parallel with the perspective axis $I\Omega$, Fig. 22, Plate XII, provided the following relation remain satisfied:

$$s\Omega : sx' = s'\Omega : s'z'.$$

For any other point B, photographed as b and b' in the picture planes MN and $M'N'$ respectively, the following proportional equation should be fulfilled:

$$s\beta : sx_0 = s'\beta : s'z_0.$$

The triangles sx_0x', $s\beta\Omega$ and $s'z_0z'$, $s'\beta\Omega$ being, respectively, similar, x_0x' must be equal to z_0z' (as $\beta\Omega$ is common to both triangles $s\beta\Omega$ and $s'\beta\Omega$), which means the spaces on the scales XX'' and zz'' are to be identical in numerical value. The two scales (or either of them) may, if more convenient, be placed beyond s or s', f. i. at tt'', in which case

$$s\beta : st_0 = s\beta : sx_0 = s'\beta : s'z_0.$$

It should be noted that the scale is now to be read from t' toward t_0. It may be stated generally that the scales should be placed parallel with the "perspective axis" $I\Omega$ and at distances from the "kernel points" directly proportional to the distances of the latter from the "perspective axis" of the picture planes, their correct position being found from the horizontal projection or from the ground plane. To avoid obscurity and obliteration of details in the field of the photograph it will generally be more expedient to draw these scales outside of the picture proper.

To find the proper position of the second scale on the second picture, after the position of the scale on the first picture has been decided upon, we again refer to Fig. 21, Plate XII, where HH and $H'H'$ are the two picture traces, S and S' are the horizontal projections of the camera stations, P and P' are the traces of the principal lines ff and $f'f'$ (Fig. 22), or the horizontal

projections of the principal points, and, finally, h the selected position for the first scale.

To find the corresponding position h' of the second scale we draw a line hh parallel to SS' through h, when

$$s'i:s'h=s_1'i:s_1'h';$$

hence

$$s_1'h'=\frac{s_1'\cdot i}{s'\cdot i}\cdot s'h$$

=distance of the second scale from the "kernel point" s' in the second picture.

The conditions and relations described in the foregoing paragraphs may often prove of value in iconometric plotting; f. i., if we consider the case of a straight line L, Fig. 23, Plate XIII, the image of which appears in picture MN as l, but in the second picture $M'N'$ only a short piece l' is seen. It may be desirable to locate in the picture plane MN the reciprocal position of a point x, shown on the line l in MN, but falling outside of the picture limit of $M'N'$ on the prolongation of l'.

To find the position of x' we proceed as follows:

The pictured point x of the line l, pictured in MN, is con nected with the kernel point (s') and the line $(s')x$ is produced to its intersection (x) with Ii. After transferring the point (x) to the line iI of the second picture plane $M'N'$, to $((x))$, and connecting the latter with the "kernel point" (s), the intersection of $((x))(s)$ with l' produced will represent the point sought, x', on the prolongation of the line l'.

VIII. To Plot a Figure, Situated in a Horizontal Plane, on the Ground Plan by Means of its Perspective.

Excepting the shore lines of lakes and coasts and the outlines of marshes, figures in horizontal planes are not frequently met with in topographic surveys, and the simplest way to map these would be to expose photographic plates in a horizontal

position from a captive balloon at points of known positions and at identical or known elevations.

The mapping of such figures, when photographed on vertically exposed plates, from stations above the figure's plane is also an easy matter. It may even be done with but a single perspective view of such figure (obtained on a vertically exposed plate from a station of known position), provided we also know the difference in elevation between the camera station and the horizontal plane containing the figure, and provided we know the positions of the principal point and horizon line together with the length of the distance line (focal length) of the photographic perspective.

We have, with reference to Fig. 24, Plate XIII, HH = horizon plane of the camera station S, OO' = horizon line of the photographic perspective MN, GG = ground plane or horizontal plane coinciding with the surface plane of the lake $ABCD$, $SS_0 = h$ = difference in elevation between the camera station S and the water level of the lake.

With a given perspective *abcd* of the lake $ABCD$ in the vertical picture plane MN, known focal length, given position of the principal point P and known difference in elevation, h, between the water surface of the lake and the camera station, the projection of the lake-outline ($A_1B_1C_1D_1$) in horizontal plan may be drawn.

The ground line O_0O_0' (line of intersection of ground plane GG with the vertical picture plane MN) is drawn through P_0 (horizontal projection of P) parallel with the horizon line OO', PP_0 being equal to h (measured in the plotting-scale). If we now project the pictured points a, b, c, d upon $O_0O_0' = a_0$, b_0, c_0, d_0, the radials from the foot S_0 of the station S drawn through the points a_0, b_0, c_0, d_0, will pass through the corresponding points of the lake shore-line A_1, B_1, C_1, D_1 that are to be plotted.

Referring to the vertical plane passing through the camera station S and through the pictured point a (it intersects the ground plane in S_0A_0 or in S_0A_1) we find from the similar triangles

SS_0A_1 and aa_0A_1 the horizontal distance S_0A_1 from the camera station to the point sought, either graphically or arithmetically.

Imagining the vertical plane SS_0A_1 to be revolved about S_0A_1 until it coincides with the ground plane GG, the points S and a will assume the positions (S) and (a), Fig. 24, Plate XIII, and the line $(S)(a)$ will pass through A_1, hence A_1 may be located in the ground plane as the intersection of $(S)(a)$ with S_0a_0. The same may be done for the other points B_1, C_1, and D_1 by revolving the vertical planes SS_0B_1, SS_0C_1, and SS_0D_1 about S_0b_0, S_0c_0, and S_0d_0 into the ground plane GG to locate the positions of B_1, C_1, and D_1.

To avoid the drawing of so many auxiliary lines on the working- or plotting-sheet, these constructions are preferably made on a separate sheet of paper, and the following method may be adopted:

The vertical planes passing through S_0a_0, S_0b_0, S_0c_0, and S_0d_0 may be supposed to be revolved about SS_0, as common axis of rotation, until they all coincide with the principal plane SS_0P_0, Fig. 25, Plate XIV, the surface of the paper representing the principal plane, when HH = trace of the horizon plane in the principal plane, MN = trace of the picture plane in the principal plane, GG = trace of the ground plane in the principal plane, $SS_0 = h$ = difference in elevation between the station S and the ground plane GG, measured in the plotting-scale, $SP = S_0P_0$ = true length of the focal distance of the photograph MN.

The radials S_0a_0, S_0b_0, S_0c_0, and S_0d_0 are laid off upon the line GG from $S_0 = S_0(a_0)$, $S_0(b_0)$, $S_0(c_0)$, and $S_0(d_0)$, and the verticals $(a_0)(a)$, $(b_0)(b)$, $(c_0)(c)$, and $(d_0)(d)$ are made equal to the ordinates aa_0, bb_0, cc_0, and dd_0, respectively, measured on the picture.

Radials drawn through (a), (b), (c), and (d) from S will cut off on the line GG the horizontal distances $S_0(A)$, $S_0(B)$, $S_0(C)$, and $S_0(D)$. These distances, laid off on the radials S_0a_0, S_0b_0, S_0c_0, and S_0d_0, on the plotting-sheet will locate, in

the scale of the map, the plotted positions of the characteristic points A_1, B_1, C_1, and D_1 of the lake, with reference to the ground line O_0O_0', which is identical on the plotting-sheet with the picture trace.

We may reach the same results by utilizing the orthogonal projections of the points a, b, c, and d and those of A_1, B_1, C_1, and D_1 into the principal plane instead of revolving the vertical planes separately into the principal plane, as done above.

With reference to Fig. 26, Plate XIV, we would then have:

PP = principal plane, MN = picture plane, HH = horizon plane, containing the camera station S, GG = ground plane or surface plane of the lake $ABCD$.

If we draw the radials S_0a_0, S_0b_0, S_0c_0, and S_0d_0 from S_0 (the orthogonal projection of S in GG) through the orthogonal projections of the pictured points a, b, c, d on the ground line O_0O_0', the points sought will fall upon those radials. After projecting the points a, b, c, and d, in the picture plane MN, upon the principal line ($=\alpha$, β, γ, and δ) the radials $S\alpha$, $S\beta$, $S\gamma$, and $S\delta$ (drawn in the principal plane PP) will locate the points α_0, β_0, γ_0, and δ_0, respectively, upon the line S_0P_0 (in the ground plane), and these represent the orthogonal projections of the points A, B, C, and D in GG upon S_0P_0. Hence the points A, B, C, and D may be found by erecting perpendiculars upon S_0P_0 in α_0, β_0, γ_0, and δ_0, respectively, and their points of intersection with the radials S_0a_0, S_0b_0, S_0c_0, and S_0d_0, respectively, will be the positions of the plotted points A, B, C, and D.

Also this construction is preferably made upon a separate sheet of paper, Fig. 27, Plate XV, where the radials S_0a_0, S_0b_0, S_0c_0, and S_0d_0 are drawn through their corresponding points on the plotted picture trace or ground line O_0O_0', but the rest of the construction is made on the separate sheet of paper, considering the surface of the latter to coincide with the principal plane (Fig. 28, Plate XV, where the designations are the same as in Fig. 25, Plate XIV).

The points δ, β, α, and γ on the line PP_0 (principal line) represent the projections into the principal plane of the pictured points a, b, c, and d, their positions being found by transferring the ordinates dd_0, bb_0, aa_0, and cc_0 of the pictured points d, b, a, and c to PP_0 from P_0, $P_0\delta = dd_0$, $P_0\beta = bb_0$, $P_0\alpha = aa_0$, and $P_0\gamma = cc_0$.

The radials from S through δ, β, α, and γ locate the points δ_0, β_0, α_0, and γ_0 on the line GG or on S_0P_0, and by transferring the distances $S_0\delta_0$, $S_0\beta_0$, $S_0\alpha_0$, and $S_0\gamma_0$, Fig. 28, Plate XV, to the principal line S_0P_0, Fig. 27, Plate XV, and drawing lines through δ_0, β_0, α_0, and γ_0 parallel with O_0O_0', their intersections with the corresponding radials S_0d_0, S_0b_0, S_0a_0, and S_0c_0 will locate the plotted positions D_1, B_1, A_1, and C_1 of the points D, B, A, and C of the shore line of the lake.

IX. To Draw the Horizontal Projection of a Plane Figure ABCD on the Ground Plan by Means of the So-called "Method of Squares," if its Perspective in Vertical Plane, abcd, and the Elements of the Perspective are given.

If we imagine the figure covered with a net of squares in such manner that one set of sides is parallel with, while the other is perpendicular to, the ground line, such net may be used to draw the outline of the figure upon the ground plan. It will only remain necessary to cover the pictured figure *abcd* with the *perspective* of the net that has been selected for the ground plan. The lines representing the squares in perspective must have the proper relation with reference to both, the principal ray and the horizon line, to conform with the net in the ground plan.

The simplest disposition of the lines forming this auxiliary net is the one mentioned above, with one set of sides parallel with, and the other perpendicular to, the horizon line; still, any other disposition of the net lines or sides may be made: they

may form equal-sized squares or not and their directions may include any angle.

In Fig. 29, Plate XVI, in illustration of this method, the lines of the perspective, corresponding to those sides of the rectangular figures that had been drawn at right angles to the ground line O_0O_0', will vanish in the principal point P, while those drawn parallel with the ground line O_0O_0' will be parallel with the horizon line OO'.

Selecting the lines of this rectangular system so that one line of each system passes through each one of the characteristic points a, b, c, and d of the pictured lake, the perspective of this net will appear as shown by the fine lines in Fig. 29, Plate XVI, where O_0O_0' represents the ground line of the picture plane MN.

If we again plot in the principal plane SS_0P_0P, Fig. 30, Plate XVI, and retain the same designations as in Fig. 25, Plate XIV, the points δ_0, β_0, α_0, and γ_0 will represent, in the ground plane GG, the intersections of the horizontal projection of the principal ray $SP=S_0P_0$ with those net lines that had been drawn parallel with the ground line through D, B, A, and C.

After plotting the picture trace O_0O_0', of the perspective MN, Fig. 29, Plate XVI, in the ground plan by means of the radials S_0a_0, S_0b_0, etc., Fig. 31, Plate XVII, the distances $S_0\delta_0$, $S_0\beta_0$, etc., taken from Fig. 30, Plate XVI, and laid off upon S_0P_0, Fig. 31, Plate XVII, will locate the intersections of S_0P_0 with those net lines (parallel with O_0O_0') in the ground plan that correspond to the lines $d\delta$, $b\beta$, etc., of the perspective MN, Fig. 29, Plate XVI.

If we now transfer the points a_0', P_0, b_0', d_0', and c_0' from Fig. 29, Platc XVI, to the edge of a paper strip and place the latter upon the picture trace O_0O_0', Fig. 31, Plate XVII, that the points P_0 of both will coincide, then the lines $a_0'A_1$, $b_0'B_1$, etc., drawn parallel with S_0P_0 will represent those net lines that are perpendicular to the ground line O_0O_0', and the plotted positions A_1, B_1, C_1, and D_1 of the points A, B, C, and D are

treated on the ground plan as the intersections of corresponding net lines of both systems as indicated in Fig. 31, Plate XVII.

The points A_1, B_1, C_1, and D_1 will, of course, also be bisected by the radials S_0a_0, S_0b_0, S_0c_0, and S_0d_0, which fact may make some other disposition of the net lines more desirable for a figure of a different shape.

When the figure is bounded by a sinuous perimeter, the squares of the net should be selected sufficiently small to enable the draughtsman to draw the perimeter sections falling within each square sufficiently accurate to obtain a correct reduction representing the general course of the figure's outline.

X. The "Vanishing Scale."

We had seen—Fig. 31, Plate XVII—that the radials drawn from the so-called foot s_0 of the station S represent directions to the points A_1, B_1, C_1, and D_1 in the ground plane. If we now could determine from the perspective the distances (S_0A_1, S_0B_1, etc.) from the foot S_0 of the station to the points to be plotted their location in the ground plane would become an easy matter.

The distances S_0A_1, S_0B_1, etc., may be determined from the perspective by means of the so-called vanishing scale, which may be constructed as follows, with reference to Fig. 32, Plate XVII, where MN = trace of picture plane, HH = trace of horizon plane, and GG = trace of ground plane, all in the principal plane, and where SS_0 = elevation of the station S above the ground plane GG, or above the foot S_0 of the station.

A scale of equal parts is laid off upon GG to both sides of P_0 and radials are then drawn from S through the graduation-marks. Their intersections with MN form the so-called vanishing scale which may serve to locate the distances from the foot S_0 of the station S to points that are to be plotted in the ground plane from the picture.

The picture trace O_0O_0', Fig. 33, Plate XVIII, may have been plotted and the radials S_0a_0, S_0b_0, etc., may have been drawn on the working-sheet. It is desired to locate the position A_1 of a point A in the ground plane that is pictured as a in MN, Fig. 34, Plate XVIII, by means of the vanishing scale.

Take the ordinate aa_0 from the photographic perspective MN (the vertical distance of a above the ground line O_0O_0') and lay it off upon the vanishing scale P_0P, Fig. 32, Plate XVII, from P_0, equal to P_0X.

The line ax in the picture plane MN, Fig. 34, Plate XVIII, drawn parallel with the horizon line OO' and passing through a, is the perspective of the line A_1x, drawn parallel with the ground line and passing through A_1, Fig. 33, Plate XVIII, in the ground plane. Hence, if we lay off S_0X, Fig. 32, Plate XVII, upon S_0P_0, from S_0, Fig. 33, Plate XVIII, the point A_1 in the ground plane will be situated upon the line XA_1, drawn parallel with the ground line O_0O_0' through X. The plotted position A_1 of the point A will be at the intersection of the radial S_0a_0 with this line XA_1.

CHAPTER V.

PHOTOGRAPHS ON INCLINED PLATES.

Until now we have regarded phototopographic plates exposed in vertical planes, and although the general use of inclined plates is not recommended for phototopographic purposes on account of the complications that will arise in the generally simple constructions underlying the iconometric plotting from vertically exposed plates, and because the relations that exist between the elements of the perspective and the orthogonal projection into horizontal plan will not be so readily recognized. Occasions may arise, however, where the selection of the available or accessible stations will be so circumscribed as to make exposures on inclined plates a necessity (to insure a good control of the inaccessible terrene forms). Photographs may also have been obtained from balloons or with an ordinary camera not supplied with devices for adjusting the plate into vertical plane, or photographs originally taken for illustrative purposes may perchance find use for iconometric plotting.

With reference to Fig. 35, Plate XIX, we have PP=principal plane, HH=horizontal plane passing through the nodal point of the camera-lens at station S, GG=ground plane, MN=picture plane, $O'P$=trace of the picture plane MN in the horizon plane HH, $O_0'P_0$=ground line of the picture plane, S_0=foot of the station S, $P'P_0$=principal line of the picture plane, P'=principal point of the perspective MN, SS_0=vertical of the station S. It pierces the ground plane in the foot of the station and passes through the picture plane MN above (or below) the horizon line at s. The point s is the vanishing point

for the perspectives of all vertical lines that may be pictured in MN. $P'SP = P'sS = \alpha =$ angle of inclination of the plate MN, $SP =$ perpendicular through S to the horizon line $O'P$, $SA =$ line of direction from S to a point A, pictured as a in MN.

If we revolve SP in the vertical plane PP about P until SP falls within the picture plane, the point S will fall into (S) and the line Sa will fall into $(S)a$.

The vertical plane, passing through SS_0 and containing the line SA, will intersect the ground plane in S_0a_0. If we revolve the line S_0P_0 within the vertical plane PP about P_0 until S_0P_0 falls into the picture plane MN, the point S_0 will fall into (S_0) and the trace S_0a_0 will have assumed the position $(S_0)a_0$.

The intersection A_0 of the trace S_0a_0 with the line of direction Sa would locate the plotted position in GG of the pictured point a.

The line sa intersects the ground line in a_0, and S_0a_0 will be the radial in the ground plane from the foot S_0 of the station S that passes through the plotted position (in GG) of A_0. To find A_0 on S_0a_0 we first locate in the picture plane the intersection (A) of the revolved lines $(S)a$ and $(S_0)a_0$. This point (A), revolved within the vertical plane a_0S_0S, will locate A_0 upon S_0a_0.

To locate the position of A_0 in GG in the manner just indicated we should know the position of the line $O'P$, as well as the points S and P. These are known, or may readily be found, if the position of the principal point P', the length of the distance line SP', and the value of the angle of inclination α are known.

When a photographic plate is purposely exposed in an inclined position in a surveying camera, it will generally be done in such manner that the principal line ff' still coincides with the intersection of the picture plane MN and the principal plane PP, Fig. 35, Plate XIX.

When the angle of inclination α is an angle of elevation (depres-

sion) the horizon line $O'P$ will fall below (above) the line representing the horizon line of the plate when exposed vertically.

The angles of inclination for inclined plates should be observed directly in the field, and if the constant focal length of the camera $= f$ is known, the line SP may be found as the hypothenuse of the right-angle triangle having the angle $= \alpha$ and adjoining side $= f = SP'$.

A. To Plot the Picture Trace of an Inclined Plate.

To plot the picture trace the horizontal angle included between the optical axis of the inclined camera and the horizontal direction to some known point should be known or measured.

Should the length $S'S_1'$, Fig. 36, Plate XX, and the position of the line connecting two camera stations be known and also the position of a third point A, visible from both stations, no instrumental measurement of a horizontal angle α need be made, provided the plates containing the pictures a of the third point A are oriented in such manner that the picture a of that third point be bisected by the vertical thread, by the principal line ff' of the perspective.

We have with reference to Fig. 36, Plate XX: S' = plotted position of the station S, $S'S_1'$ = plotted length and direction of the base line, SS = elevation of the station S (laid off in the reduced plotting-scale), Fig. 37, Plate XXI. The horizontal angle α (at S', Fig. 36, Plate XX), included between the plotted base line $S'S_1'$ and the principal plane (or the horizontal projection $S'P_0$ of the optical axis SP') may have been observed in the field.

We revolve the line $S'S$ about $S'P_0$, Fig. 36, Plate XX and Fig. 37, Plate XXI, into the plotting-plane, when it will assume the position $S'(S)$, and erect at (S) a line $(S)(P)$ perpendicular to $S'(S)$. The angle of inclination of the plate $MN = \gamma$ is laid off from (S) upon $(S)(P)$. We make $(S)(P')$ equal to the constant focal length of the camera $= f$, when the line $(f)(f')$, drawn perpendicular to $(S)(P')$ through (P), will represent

the principal line ff' of the perspective MN, Fig. 37, Plate XXI, revolved about $S'P_0$ into the plotting-plane.

The point of intersection (s) of $(S)S'$ with $(f)(f')$ represents the vanishing point for all vertical lines that may be shown in picture MN.

The intersection P_0 of the perpendicular line $(f)(f')$ with the horizontal projection of the optical axis $S'P_0$ will be the trace of the inclined principal line ff' in the ground plane (drawing plan). The line P_0g, perpendicular in P_0 to $S'P_0$, is the ground line or the trace of the inclined picture plane MN in the drawing plan GG.

B. Plotting the Lines of Direction to Points pictured on an Inclined Photographic Plate.

The inclined picture plane MN is revolved about P_0g into the drawing or ground plane, Fig. 37, Plate XXI, when it will appear as $(M)(N)$, the principal point P falling upon $S'P_0 = (f)(f')$ in (P) and $(P)P_0$ is equal to PP_0.

To plot the direction from S' to a point A, Fig. 36, Plate XX, pictured in MN as a, we first locate the orthogonal projection a_0 of the pictured point a in the ground plane (plotting-plane). We project the image point a, Fig. 37, Plate XXI, upon ff' or upon $PP_0 = \alpha$, and describe a circle about P_0 with $P_0\alpha = P_0(\alpha)$ to locate the position (α) of the projected point on the principal line $(f)(f')$, revolved into the ground plane. (The positions of the pictured points a in Figs. 36 and 37 do not correspond; both should be on the same side of ff' in the picture planes $(M)(N)$ –.)

The perpendicular to $S'P_0$, Fig. 37, Plate XXI, in α_0 and the vertical that passes through a intersect each other in a_0. The point a_0, Fig. 36, Plate XX, is located on the plotting-sheet as the intersection of $(a_0)\alpha_0$ (perpendicular to $S'P_0$ through (α_0) –) and $(a)a_0$ (parallel with $S'P_0$ or with $(f)(f')$ through (a) –).

$S'a_0$, Fig. 36, Plate XX, will be the horizontal projection

(in the plan) of the line of direction (or radial) from S' to the point A to be plotted.

C. Determination of the Altitudes of Points pictured on an Inclined Plate.

It is desired to find the elevation H of the point A, pictured in MN as a, above the ground plane GG. With reference to Fig. 36, Plate XX, the elevation $aa_0 = \alpha\alpha_0$, in Fig. 37, Plate XXI, corresponds to $(\alpha)\alpha_0$.

If D = horizontal distance of the plotted point A from the station S' (taken from the plotting-sheet), $h = \alpha\alpha_0 = aa_0 = (\alpha)\alpha_0$, H = elevation of A above GG, and $d = S'a_0$ (Fig. 36), taken from the plotting-sheet, then the elevation H of the point A may be found, either graphically from a diagram, Fig. 39, Plate XXIII, or it may be computed from the relation

$$H = \frac{D \cdot h}{d}.$$

D. Applications of Prof. Guido Hauck's Method.

The constructions described for locating the horizontal directions to points photographed on inclined plates may be greatly simplified by applying Prof. Hauck's method, utilizing the properties of the "kernel points" of two photographs obtained from different stations, but covering the same terrene.

In Fig. 38, Plate XXII, S and S' may represent the two camera stations, S_0 and S_0' are the foot points of S and S' respectively, MN and $M'N'$ may represent the inclined picture planes, both containing the images a and a', respectively, of a point A and the pictures s' and s of the stations S' and S. The orthogonal projections of the pictured points a and a' in the ground plane are α_0 and α_0'. A_0 is the orthogonal projection of A into the ground plane GG. We had seen that Σ, s', and π are "kernel points"

for the picture plane MN and Σ', s, and π' are the "kernel points" for $M'N'$.

The line connecting a and s' in MN and the line $a's$ in $M'N'$ intersect each other in the same point Ω of the line of intersection of the two pictures planes (MN and $M'N'$), and they also intersect the ground lines gg' in π and π' respectively.

All lines in MN connecting s' with pictured points and those in $M'N'$ connecting s with the images in $M'N'$ of the same points will intersect each other in points Ω of the line of intersection ("perspective axis") of the picture planes.

The points Σ and Σ' (the intersections of the verticals passing through the camera stations S and S' with the inclined picture-planes MN and $M'N'$) are the vanishing points for the pictures of all verticals shown in the negatives. Whenever the pictures contain images of vertical lines, the intersections of their pictures would locate Σ and Σ' on MN and $M'N'$ respectively; still, when the picture plane is inclined in such a way that the principal line of the same would coincide with that of the vertically exposed plate (if the former were revolved about a line as axis passing through the second nodal point and being parallel with the horizon line OO', or HH'), the kernel point Σ may more readily be located upon jj', as previously shown for s in Fig. 37, Plate XXI.

The horizontal direction S_0A_0 ($S_0'A_0$) intersects the ground line gg' of MN ($M'N'$) in a_0 (respectively in a_0'), Fig. 38, Plate XXII. In order to locate the position of A_0 with reference to a on MN (to a' on $M'N'$) we connect a and Σ (also a' with Σ'), which line locates a_0 (and a_0') upon the ground line gg' of the picture plane MN (and $M'N'$ respectively).

The interesction A_0 of the lines S_0a_0 and $S'a_0'$ will now give the plotted position in the ground plane GG of the point A.

CHAPTER VI.

PHOTOTOPOGRAPHIC SURVEYING METHODS.

From the preceding chapters we find that in order to utilize for iconometric purposes the data contained in a photographic perspective we should know:

First. The three constants or elements of the perspective, which are the focal length, together with the horizon and the principal line, or the focal length and the principal point, together with either the horizon line or the principal line of the perspective.

Second. The position of the picture plane with reference to fixed points of the terrene, which means the elements for the orientation of the picture trace in the plotting-plane.

To plot the position of any geodetic point in both the horizontal and in the vertical sense, we should know, or be able to ascertain,

First. The horizontal angles included between the principal plane and the lines of direction from two or more stations to the geodetic point.

Second. The angle of elevation (or depression) which is the vertical angle included between the horizon plane and the line of direction to the geodetic point.

If the constants or the elements of the perspective are known, the geodetic elements (the horizontal and vertical angles) needed for plotting the position of the geodetic point may be ascertained either graphically or arithmetically.

Phototopographic methods being generally applied with a view toward obtaining a graphic record of the measurements in the

form of cartographic representation of the terrene, we shall give in these pages principally *graphic* solutions of the more important problems met with in phototopography.

I. Analytical or Arithmetical Phototopographic Methods.

A. Method of Prof. Jordan.

In Chapter I, section III, mention has been made of Prof. Jordan's map of the oasis "Dachel" and village "Gassr-Dachel," based on Remelé's photographs. Care was exercised to expose the plates in vertical plane, and horizontal directions to at least three points of each photograph were measured instrumentally to obtain the required data for the orientation of the pictures. Vertical angles to at least two such points for every picture were also observed to give the means for locating the horizon lines of the pictures, thus enabling the draughtsman to deduce the elevations of other points pictured on the photographs. With reference to Fig. 40, Plate XXIII, we have:

OO' = horizon line of photographic perspective MN;
ff' = principal line;
P = principal point;
S = second nodal point (focus) of camera lens;
$SP = f$ = focal length of picture MN = principal ray;
a, b, and c = images of three points A, B, and C;
α_1, α_2, and α_3 = horizontal angles $a'SP$, $b'SP$, and $c'SP$;
SN = direction of the meridian passing through the station S;
ϕ_1 ϕ_2, and ϕ_3 = azimuthal angles NSa', NSb', and NSc' respectively;
H_1, H_2, and H_3 = elevations of the points A, B, and C above the plane of reference or ground plane.

The photographic plate MN having been exposed in vertical plane, it will be evident that for the three points a, b, and c respectively the abscissæ x_1, x_2, and x_3 should be

$$x_1 = f \tan \alpha_1,$$
$$x_2 = f \tan \alpha_2,$$
$$x_3 = f \tan \alpha_3,$$

or
$$x_2 - x_1 = f(\tan \alpha_2 - \tan \alpha_1) = f \cdot \frac{\sin(\alpha_2 - \alpha_1)}{\cos \alpha_1 \cos \alpha_2}$$

and
$$x_3 - x_2 = f(\tan \alpha_3 - \tan \alpha_2) = f \cdot \frac{\sin(\alpha_3 - \alpha_2)}{\cos \alpha_3 \cos \alpha_2}.$$

The values for $(x_2 - x_1)$ and $(x_3 - x_2)$ may be scaled off directly on the negative, MN, and the values for $(\alpha_2 - \alpha_1)$ and $(\alpha_3 - \alpha_2)$ may be taken from the field records of the observed horizontal angles, when the value for $\frac{\cos \alpha_3}{\cos \alpha_1}$ may be computed by means of the formula

$$\frac{x_2 - x_1}{x_3 - x_2} = \frac{\cos \alpha_3}{\cos \alpha_1} \cdot \frac{\sin(\alpha_2 - \alpha_1)}{\sin(\alpha_3 - \alpha_2)}.$$

If we substitute $\tan \gamma$ for $\frac{\cos \alpha_3}{\cos \alpha_1}$, and as

$$\frac{1 + \tan \gamma}{1 - \tan \gamma} = \tan(45 + \gamma),$$

we may write

$$\tan(45 + \gamma) = \frac{1 + \dfrac{\cos \alpha_3}{\cos \alpha_1}}{1 - \dfrac{\cos \alpha_3}{\cos \alpha_1}} = \frac{\cos \alpha_1 + \cos \alpha_3}{\cos \alpha_1 - \cos \alpha_3}$$

$$= \frac{\cos \dfrac{\alpha_1 + \alpha_3}{2} \cos \dfrac{\alpha_1 - \alpha_3}{2}}{\sin \dfrac{\alpha_1 + \alpha_3}{2} \sin \dfrac{\alpha_1 - \alpha_3}{2}} = \cot\left(\frac{\alpha_1 + \alpha_3}{2}\right) \cot\left(\frac{\alpha_1 - \alpha_3}{2}\right);$$

hence
$$\tan \frac{\alpha_1 + \alpha_3}{2} = \cot(45 + \gamma) \cot\left(\frac{\alpha_1 - \alpha_3}{2}\right).$$

From this equation $\alpha_1+\alpha_3$ may be computed.
By inspection we find from Fig. 40, Plate XXIII,

$$\alpha_3-\alpha_2=\phi_3-\phi_2=\varepsilon_2,$$

$$\alpha_2-\alpha_1=\phi_2-\phi_1=\varepsilon_1.$$

By adding these two equations we obtain

$$\alpha_1-\alpha_3=\phi_2-\phi_3.$$

Knowing $(\alpha_1+\alpha_3)$ and $(\alpha_1-\alpha_3)$ we can readily find α_1 and α_3;

also $$\alpha_2=\alpha_1+\varepsilon_1$$

or $$=\alpha_3-\varepsilon_2.$$

We had found

$$x_2-x_1=f\frac{\sin(\alpha_2-\alpha_1)}{\cos\alpha_1\cos\alpha_2}=f\frac{\sin\varepsilon_1}{\cos\alpha_1\cos\alpha_2};$$

hence $$f=\frac{(x_2-x_1)\cos\alpha_1\cos\alpha_2}{\sin\varepsilon_1},$$

and $$x_3-x_2=f\frac{\sin(\alpha_3-\alpha_2)}{\cos\alpha_3\cos\alpha_2}=f\frac{\sin\varepsilon_2}{\cos\alpha_3\cos\alpha_2},$$

whence $$f=\frac{(x_3-x_2)\cos\alpha_3\cos\alpha_2}{\sin\varepsilon_2}.$$

Thus two elements of the perspective MN, the focal length f, and the principal line ff' (given by the abscissæ x_1, x_2, and x_3), may be found.

With the aid of the observed vertical angles β, the third element, the horizon line OO', may now be located on the photograph.

The vertical angle $\beta_3 = cSc'$ having been observed at S to the point C we find

$$cc' = y_3 = Sc' \cdot \tan \beta_3 = \frac{f}{\cos \alpha_3} \cdot \tan \beta_3,$$

and for the point a the vertical distance to the horizon line would be

$$aa_1 = y_1 = Sa' \cdot \tan \beta_1 = \frac{f}{\cos \alpha_1} \tan \beta_1.$$

The horizon line OO' will be the common tangent to two circles, one described with the radius $= \dfrac{f}{\cos \alpha_1} \tan \beta_1$ about a and the other with a radius $= \dfrac{f}{\cos \alpha_3} \tan \beta_3$ about c.

At least two vertical angles having been observed for each exposed plate, the horizon line OO' may thus be located and marked upon the negative, when the principal point P may also be located on OO' by means of the principal line ff', the latter being tangent to the three circles described about a, b, and c with the radii x_1, x_2, and x_3 respectively.

B. Method of Dr. Le Bon.

Dr. G. Le Bon (who used his instrument chiefly for the plotting of ancient buildings and monuments in India) provided the ground-glass plate of his camera with a net of squares, each square having 1 cm. sides, one set of the latter being drawn parallel with the horizon, while the second set of lines is parallel with the principal line of the perspective. The lines representing the horizon and principal lines are again subdivided into millimeters.

This arrangement enables the operator to obtain the measurements of objects directly by inspection of the image on the graduated ground-glass plate.

To determine the dimensions of the front of a building Dr. Le Bon measures a certain length directly upon the same and then takes a picture by exposing a photographic plate in vertical plane and parallel with the base of the front (façade) of the building.

For example, to find

First. The distance D of an object, the height H of which is not known, Fig. 41, Plate XXIII:

Two stations S and S' are occupied on a base line B (which is measured directly in the field) laid off in a direction perpendicular to the base of the object.

If the height of the image measured on the ground glass at the first station is h, at the second station h', and if the focal length for both exposures be the same and $=f$, then

$$D:H=f:h,$$

and for the second station S'

$$(D+B):H=f:h'.$$

h and h' being known—they may be measured directly on the negative or on the ground-glass plate—we find, after dividing the second equation by the first,

$$\frac{D+B}{D}=\frac{h}{h'},$$

or
$$\frac{B}{D}=\frac{h}{h'}-1=\frac{h-h'}{h'};$$

whence
$$D=\frac{Bh'}{h-h'}.$$

Second. The height H of an object is to be found when the fractional length H' has been obtained by direct measurement (Fig. 42, Plate XXIV).

On the image of the object—on the graduated ground-glass plate—the lengths for the heights h and h' may be read off directly, and as H' is also known, we find H from the equation

$$H = H' \frac{h}{h'}.$$

C. Method of L. P. Paganini (Italian Method).

This method has been extensively used for the new topographic survey of the kingdom of Italy and for the Colonial possessions in East Africa ("Eritrea").

COMPUTATION OF THE ELEMENTS OF THE PHOTOGRAPHIC PERSPECTIVE WHICH ARE NEEDED FOR THE ICONOMETRIC PLOTTING.

1. Determination of the Focal Length of the Photographic Perspective.

(a) When the Reference Point is Bisected by the Principal Line of the Perspective.

A triangulation point S, Fig. 121, Plate LX, may be visible from the camera station V. The camera is directed toward S in such manner that the image s of the distant peak S is bisected by the vertical thread ff'.

V = camera station or the point of view of the perspective MN;

P_1 = principal point of the photograph;

VP_1 = focal length or distance line of the perspective, denoted by f;

S' = orthogonal projection of S in the horizontal plane which passes through V;

VS_1' = horizontal distance from V to S, designated by D;

SS' = apparent difference in elevation between V and S, designated by L.

After having carefully measured the ordinate $Ps = y$ on the negative, we can determine the focal length from the equation

$$f = \frac{D \cdot y}{L}.$$

Example No. I.—The station V may be occupied over the centre of the triangulation point Reale Accampamento and the bisected point S be the signal upon Cian del Lei. The camera having been leveled and adjusted over Reale Accampamento is turned in azimuth until the signal Cian del Lei is bisected by the vertical thread ff' and the first plate is then exposed (Fig. 122, Plate LXI).

The focal distance, read off on the scale a of the lens tube $= 244.5$ mm., and the values for D and L, taken from the records of the new trigonometrical survey of Italy, are

D = distance from Reale Accampamento (signal) to Punta Cian del Lei (signal)	= 3270.7 m.
Elevation of station mark at Punta Cian del Lei	= 2811.72 m.
Elevation of camera horizon at Reale Accampamento	= 2191.80 m.
Difference of true elevation	= 619.92 m.

The ordinate y, carefully measured on the negative (from the principal point P to the image s of the point Cian del Lei) gave 46.25 mm.

Computation of L:

True difference in elevation	= 619.92 m.
Correction for curvature and refraction	= −0.72 m.
L = apparent difference in elevation	= 619.20 m.

Computation of f:

$$
\begin{aligned}
\log D &= \log 3270.7 = 3.5146407 \\
\log y &= \log 0.04625 = 8.6651117 \\
\operatorname{colog} L &= \operatorname{colog} 619.20 = 7.2081691 \\
\hline
\log f &= 9.3879215 \\
f &= 244.30 \\
\text{Scale-reading for } f \text{ was} &= 244.50 \\
\hline
\text{Difference} &= 0.20 \text{ mm.}
\end{aligned}
$$

(b) The Image of the Reference Point Falls to either Side of the Principal Line of the Photographic Perspective.

If the image s of the reference point S be to either side of the vertical thread ff' of the perspective MN, Fig. 123, Plate LX, the principal ray VP making an angle e with the horizontal direction VS' to the reference point s, then the value $VP=f$ may be found as follows:

d = horizontal distance Vs' (Fig. 123);
y and x = coordinates of the image s;
D = horizontal distance between the camera station V and the reference point S, and
L = apparent difference in elevation between V (or s') and s.

From the similar triangles VSS' and Vss' we find

$$\frac{L}{D}=\frac{y}{d};$$

hence

$$d=\frac{D \cdot y}{L}.$$

From the horizontal triangle $s'PV$ we find

$$d=\frac{f}{\cos e};$$

hence $$f=\frac{D\cdot y}{L}\cos e.$$

Example No. II.—In the panorama (series of ten photographic perspectives) obtained September 21, 1884, vertically above the trigonometrical point (of the new Italian geodetic triangulation system), near Reale Accampamento of Valsavaranche, there is one plate (P^5, Fig. 122, Plate LXI) which contains the image of the triangulation station Punta Ruja (signal).

The horizontal angle ω, between the optical axis of the camera for this plate and the horizontal direction to Ruja (signal), is=

$$5^\circ\ 49'\ 27''.75.$$

The horizontal distance: Reale Accampamento—Ruja $=D=$ 5804.2 m. and the elevation of Ruja $=3173.5$ m. are taken from the triangulation data.

By careful measurement y is found to be $=41.45$ mm.

It is desired to find the focal length, f, for this perspective, which may be obtained, approximately, by reading the graduation on the objective tube $=244.50$ mm.

Computation of L:

Elevation of station mark at Ruja	=3173.5 m.
Elevation of the camera horizon (OO')	=2191.8 m.
True difference in elevation	= 981.7 m.
Correction for refraction and curvature	= − 2.3 m.
Apparent difference in elevation	= 979.4 = L

Computation of f:

$$\begin{aligned}
\log D &= \log 5804.2 \text{ m.} &&= 3.7637424\\
\log y &= \log 0.04145 \text{ m.} &&= 8.61175245\\
\log \cos \omega &= \log \cos 5^\circ\ 49'\ 27''.75 &&= 9.9977522\\
\text{colog } L &= \text{colog } 979.4 &&= 7.0090399\\
\hline
&& \log f &= 2.3880590\\
&& f &= 244.38 \text{ mm.}\\
&& \text{Scale reading} &= 244.50 \text{ mm.}\\
\hline
&& \text{Difference} &= \quad 0.12 \text{ mm.}
\end{aligned}$$

Had we measured the abscissa x instead of the ordinate y the focal length for the negative could have been computed by the formula

$$f = x \cot \omega.$$

Example No. III.—The measured value for x may have been found to be $= 24.90$ mm.

Computation of f:

$$\begin{aligned}
\log x &= \log 24.90 &&= 1.3961993\\
\log \cot \omega &= \log \cot 5^\circ\ 49'\ 27''.75 &&= 0.9913737\\
\hline
&& \log f &= 2.3875730\\
&& f &= 244.103 \text{ mm.}
\end{aligned}$$

2. Orientation of the Picture Traces.

There exists a close connection between the phototopographic stations and the new triangulation of Italy. A generous disposition of the trigonometric points had been made with the special purpose in view that they were to serve as the foundation for the subsequent topographical survey. These points have

been carefully selected, their positions have been precisely computed, and their locations have been permanently marked in the field, irrespective of the character of the surrounding topography or of the order of triangulation to which the point may belong. This large number of triangulation points not only facilitates the application of the phototopographic surveying method and assures the accurate determination of the panorama stations (in the horizontal and vertical sense), but it also greatly simplifies the subsequent iconometric plotting, as the greater part of the perspective contains one, two, or more pictured triangulation points, notwithstanding the instrument commands a field of view of but 42° horizontally. Two adjoining plates have a common margin of an angular width of 3°, reducing the effective field of view of one plate to 36° (Fig. 124, Plate LXII).

Thus the picture traces are easily oriented for the iconometric work, the salient topographic features (deduced from the perspectives) may be frequently checked, and such negatives (containing the images of triangulation points) may also serve to verify the focal length f of the panorama pictures, check the position of the principal point P, and they give the means for testing the location of the horizon line OO' on the pictures.

The perspective MN, Fig. 125, Plate LXII, may contain the images of two trigonometrical points S and S'.

In the preceding pages it has been shown that the horizontal distances, d and d', from the camera station V to the pictured points S and S' may be found from the relations

$$d=\frac{Dy}{L} \quad \text{and} \quad d'=\frac{D'\cdot y'}{L'}.$$

In the triangle VS_1S_1' we know the lengths of two sides, d and d', and also the value of the included angle, S_1VS_1', which may be either measured directly at the camera station or, when the latter is also a triangulation station, the value for the angle may be taken from the triangulation records.

The other two angles, γ and δ, of this triangle may now be found as follows:

$$\tan\frac{\gamma-\delta}{2}=\frac{d'-d}{d'+d}\cot\frac{V}{2},$$

$$\gamma+\delta+V=180^\circ, \quad \text{hence} \quad \frac{\gamma+\delta}{2}=90^\circ-\frac{V}{2}.$$

If we replace $\frac{1}{2}(\gamma+\delta)$ by M and $\frac{1}{2}(\gamma-\delta)$ by N, we find after adding the equations

$$\tfrac{1}{2}[(\gamma+\delta)+(\gamma-\delta)]=M+N=\gamma,$$

and by subtracting the equations

$$\tfrac{1}{2}[\gamma+\delta-\gamma+\delta]=M-N=\delta.$$

The principal ray VP should be vertical to the horizon line OO' and both triangles VPS_1 and VPS_1' should be right-angle triangles.

Hence the focal length f should be

$$f=d\cdot\sin\gamma$$

and

$$f=d'\cdot\sin\delta.$$

To ascertain whether the pictured intersection of the cross-wires P coincides with the principal point of view P upon the perspective, the measured lengths of the abscissæ x and x' (Fig. 125, Plate LXII) should be the same as the computed values

$$x=f\cot\gamma,$$
$$x'=f\cot\delta.$$

The angles of orientation ω and ω' are:

$$\omega=90^\circ-\gamma,$$
$$\omega'=90^\circ-\delta.$$

3. Determination of the Elevations of Pictured Terrene Points.

The vertical angles of elevation α and α' of the two reference points S and S' may be computed from the equations:

$$\tan\alpha = \frac{L}{D},$$

$$\tan\alpha' = \frac{L'}{D'}.$$

These angles are either taken from the triangulation records or they may be observed directly from the camera station, and to check the position of the horizon line OO' the ordinates y and y', measured on the perspective, are compared with those computed by means of the equations

$$y = \frac{f}{\cos\omega}\tan\alpha,$$

$$y' = \frac{f}{\cos\omega'}\tan\alpha'.$$

Example No. IV.—In the panorama obtained Sept. 19, 1884, from Punta Percia (this peak is on the divide separating the valleys of the Rhêmes and the Valsavaranche) two trigonometrical stations, Punta Rouletta and Gran Punta di Nomenon, of the new Italian geodetic survey appear upon the same plate (see Fig. 126, Plate LXIII).

The following values are given for the computation:

Elevation of Punta Rouletta	= 3384.10 m.	Taken from the catalogue of triangulation points
Elevation of Punta di Nomenon	= 3488.42 m.	
Elevation of horizon of camera station (P. Percia)	= 3202.3 m.	Elevation of P. Percia + height of instrument
Distance: Percia–Rouletta = D	= 3250 m.	Measured upon the projection of the iconometric working-sheet, scale $\frac{1}{50000}$
Distance: Percia–Nomenon = D'	= 9720 m.	

The horizontal angle V (Fig. 126, Plate LXIII) at Punta Percia, included by the horizontal directions to Rouletta (signal) and Nomenon (signal), $=28^\circ\ 02'\ 30''$.

A careful measurement of the coordinates of the pictured points P. Rouletta and P. Nomenon, on the negative with a millimeter scale provided with a microscope and vernier, enabling the computer to read to 0.05 mm. (the vernier is divided to read to 1/20 of the graduation unit), produced the following values:

The coordinates of Punta Rouletta,

$$x=46.05 \text{ mm.}; \quad y=13.75 \text{ mm.}$$

The coordinates of Punta di Nomenon,

$$x'=75.40 \text{ mm.}; \quad y'=7.30 \text{ mm.}$$

It is desired to find:

(1) The focal distance for this negative $=f$, the preliminary value, read off on the scale attached to the objective cylinder, is found to be 244.50 mm.

(2) The correct position of the principal point (P), which will be fixed by the determination of the abscissæ x and x'.

(3) The position of the line of horizon OO', which will be located by ascertaining the values for y and y'.

Computation to determine the apparent differences in elevation between the camera horizon (P. Percia) and the two pictured points P. Rouletta and Punta di Nomenon.

Altitude of P. Rouletta	$=3384.10$ m.
Altitude of camera horizon	$=3202.30$ m.
True difference in elevation $=$	181.80 m.
Correction for curvature and refraction $=$	-0.71 m.
Apparent difference in elevation $=L$	$=181.09$ m.
Altitude of Punta di Nomenon	$=3488.42$ m.
Altitude of camera horizon	$=3202.30$ m.

$$
\begin{array}{rl}
\text{True difference in elevation} = & 286.12 \text{ m.} \\
\text{Correction for curvature and refraction} = & -6.35 \text{ m.} \\
\hline
\text{Apparent difference in elevation} = L' = & 279.77
\end{array}
$$

Computation of $d = \frac{D}{L} y$.

$$
\begin{aligned}
\log D &= 3.5118834 \\
\log y &= 8.1383027 \\
\text{colog } L &= 7.7421055 \\
\hline
\log d &= 9.3922916 \\
d &= 246.77 \text{ mm.}
\end{aligned}
$$

Computation of $d' = \frac{D'}{L'} y'$.

$$
\begin{aligned}
\log D' &= 3.9876663 \\
\log y' &= 7.8633229 \\
\text{colog } L' &= 7.5531989 \\
\hline
\log d' &= 9.4041881 \\
d' &= 253.62 \text{ mm.}
\end{aligned}
$$

$$
\begin{aligned}
d + d' &= 500.39 \\
d' - d &= \quad 6.85
\end{aligned}
$$

Computation of the angles γ and δ:

$$\tan \frac{\gamma - \delta}{2} = \frac{d' - d}{d' + d} \cdot \cot \frac{V}{2};$$

$$V = 28^\circ\ 02'\ 30''; \quad \frac{V}{2} = 14^\circ\ 01'\ 15'';$$

$$\gamma + \delta = 180 - V = 151^\circ\ 57'\ 30''; \quad \frac{\gamma + \delta}{2} = 75^\circ\ 58'\ 45'' = M.$$

$$
\begin{aligned}
\log (d' - d) &= \log 0.00685 &&= 7.8356906 \\
\log \cot \frac{V}{2} &= \log \cot 14^\circ\ 01'\ 15'' &&= 0.6025567 \\
\text{colog } (d' + d) &= \text{colog } 0.50039 &&= 0.3006914 \\
\hline
& \log \tan \frac{\gamma - \delta}{2} &&= 8.7389387
\end{aligned}
$$

$$\frac{\gamma - \delta}{2} = 3^\circ\ 08'\ 16''.1 = N.$$

Hence

$$
\begin{aligned}
M + N &= \gamma = 79^\circ\ 07'\ 01''.1 \\
M - N &= \delta = 72^\circ\ 50^\circ\ 28''.9
\end{aligned}
$$

(α) *Computation of the Focal Length* ($=f$).

$$f = d \cdot \sin \gamma \qquad\qquad f = d' \cdot \sin \delta$$

$$\log d = 9.3922916 \qquad\qquad \log d' = 9.4041881$$

$$\log \sin \gamma = 9.9921180 \qquad\qquad \log \sin \delta = 9.9802269$$

$$\log f = 9.3844096 \qquad\qquad \log f = 9.3844150$$

$$f = 0.242331 \text{ m.} \qquad\qquad f = 0.242334 \text{ m.}$$

Mean value for $f = 242.332$ mm.

(β) *Computation of the Abscissæ* (x *and* x') *for Platting Lines of Horizontal Directions to Pictured Points of the Terrene and for Checking the Position of the Principal Point.*

$$x = f \cdot \tan \omega \qquad\qquad x' = f \cdot \tan \omega'$$

$$\omega = 90^\circ - \gamma = 10^\circ\ 52'\ 58''.9 \qquad \omega' = 90^\circ - \delta = 17^\circ\ 09'\ 31''.1$$

$$\log f = 9.3844123 \text{ (mean log)} \qquad \log f = 9.3844123 \text{ (mean log)}$$

$$\log \tan \omega = 9.2838945 \qquad\qquad \log \tan \omega' = 9.4896222$$

$$\log x = 8.6683068 \qquad\qquad \log x' = 8.8740345$$

$$x = 46.59 \text{ mm.} \qquad\qquad x' = 74.82 \text{ mm.}$$

x meas. on plate $= 46.05$ mm. $\qquad$ x' meas. on plate $= 75.40$ mm.
difference $= \Delta x = 0.54$ mm. $\qquad$ $\Delta x' = 0.58$ mm.

Mean difference $= 0.56$ mm.

From this difference we infer that the principal point P of the photographic perspective should be transposed toward the pictured point of Punta di Nomenon by 0.6 mm.

(γ) *Computation of the Ordinates* (y *and* y') *of Pictured Terrene Points of Known Elevations to Check the Position of the Horizon Line* (OO') *on the Negative.*

$$y = \frac{f}{\cos \omega} \tan \alpha, \qquad\qquad y' = \frac{f}{\cos \omega'} \tan \alpha'.$$

Where

α = angle of elevation of Punta Rouletta $= 3^\circ\ 11'\ 30''$ } Observed from the trigonometrical station Punta Percia
α' = angle of elevation of Punta di Nomenon $= 1^\circ\ 38'\ 30''$ }

$\log f = 9.3844123$	$\log f = 9.3844123$
$\log\tan\alpha = 8.7463444$	$\log\tan\alpha' = 8.4572812$
$\operatorname{colog}\cos\omega = 0.0078820$	$\operatorname{colog}\cos\omega' = 0.0197731$
$\log y = 8.1386387$	$\log y' = 7.8614666$
$y = 13.761$ mm.	$y' = 7.269$ mm.
y measured on plate $= 13.75$ mm.	y' measured $= 7.30$ mm.
Difference $= 0.01$ mm.	Difference $= 0.03$ mm.

The correction for y is so small that it may be disregarded; the length measured on the plate for y' should be reduced by 0.03 mm. and the corrected horizon line would fall 7.27 mm. below the pictured point P. di Nomenon (Fig. 126, Plate LXIII).

(δ) *Orienting a Panorama.*

The angles of orientation of the perspective (ω and ω') regarding the two pictured triangulation stations had been found to be

$$\omega = 10^\circ\ 52'\ 58''.9$$

and

$$\omega' = 17^\circ\ 09'\ 31''.1$$

Owing to the fact that the distance D and D' in the preceding example are large in comparison with the ordinates y and y', it may be preferable first to determine f by means of the abscissæ and then to compute the values for the ordinates (y and y') based upon this value of f and the observed angles of orientation ω and ω'.

If we construct the decagon (see Fig. 124, Plate LXII) representing the horizontal projection of the ten negatives obtained at the station Punta Percia by means of the elements, obtained by observations only, we will find the direction to the principal point P of the perspective containing the pictures of Rouletta and Nomenon to be $= 350^\circ\ 00'\ 00''$.

Direction to Punta Nomenon (signal) $= 332° \ 42' \ 00'$.
Direction to Punta Rouletta (signal) $= \ 0° \ 44' \ 30''$.

From these lines of direction we find the following values for the angles of orientation:

Direction to Rouletta	$= 360° \ 44' \ 30''$	Direction to point P	$= 350° \ 00' \ 00'$
Direction to point P	$= 350° \ 00' \ 00''$	Direction to Cima Nomenon	$= 332° \ 42' \ 00''$
	$\omega = \ 10° \ 44' \ 30''$		$\omega' = \ 17° \ 18' \ 00''$
Which differ from the preceding values	$\omega = \ 10° \ 52' \ 58''.9$		$\omega' = \ 17' \ 09' \ 31''.1$
by	$\Delta\omega = \ \pm \ 8' \ 28''.9$		

This small angle $\Delta\omega$ (at V) corresponds to an abscissa Δx, which in turn represents the error in position of the pictured point P in the horizontal sense. (In the preceding example, panorama from station Percia, Sept. 19, 1884, $\Delta x = 0.56$ mm.)

From the right-angle triangle with angle at $V = \Delta\omega$ and the two sides Δx and f (Fig. 126, Plate LXIII) we find the value for Δx for our negative from the equation

$$\Delta x = f \tan \Delta\omega.$$

$$\log f = \log 242.332 \quad = 2.3844123$$
$$\log \tan 0° \ 08' \ 28''.9 = 7.3922081$$
$$\log \Delta x = 9.7766204$$
$$\Delta x = \mp 0.598 \text{ mm.},$$

representing the error in the position of the principal point of the perspective, which, however, has little influence upon the precision of the graphical operations (iconometric plotting) which are to be executed in order to transpose the topographic relief upon the chart from the photographic perspectives as long as the error in question (Δx) does not exceed 2 mm. for the entire panorama of ten plates, each controlling an angle of 36° horizontally.

4. Checking the Verticality of an Exposed Plate.

For mountain work, where the differences in elevation between the several terrene points (which are pictured on the negative) and the camera horizon are relatively great, it is important to

know whether the negative had been exposed while in vertical plan and whether the photographic perspective has a correct horizon line OO', since the ordinates of the various terrene points in question would become too long when the plate is (inclined) not vertical. Therefore to assure oneself whether the picture plane (ground-glass or negative plate) of the photo-theodolite is vertical and also whether the optical axis of the camera is horizontal (the trace of this axis upon the perspective plane is represented by the intersection P of the pictured cross-threads OO' and ff') bring the plane containing the optical axis and the "horizontal wire" OO' representing the horizon line into horizontal plan and direct the instrument to a well-defined distant point situated high above the camera horizon, and at the same time the vertical thread should be visible against the ground glass, so that the distant point may be bisected by it. If we now measure the ordinate of the elevated distant point on the ground-glass plate and repeat this measurement after revolving the camera in azimuth 180°, clamping the horizontal circle, and "transiting" the camera (revolving it about its horizontal axis of revolution 180°), the two lengths thus obtained for the ordinate of the point in question should be the same, otherwise the conditions of the apparatus are not satisfactory and the instrument should be adjusted until the two measurements give the same results.

With reference to Fig. 127, Plate LXIII, we have

VP = optical axis of the camera made horizontal and the vertical thread bisecting the distant point S;

MPA = angle of inclination of the picture plane against the vertical plane;

Po = length of ordinate of pictured point S, measured on vertical thread from P.

The plane of the perspective NM not being vertical to the optical axis, it will assume the position $N'M'$ for the indirect position of the camera (as described above) and the ordinate Po'

measured on the ground-glass plate will now be shorter than when measured ($=Po$) before. Had the picture plane been vertical originally it would have coincided with AB for both the direct and reversed observation; the ordinate measured in both positions would have been $=Ps$.

The instrument must be adjusted to make

$$Ps=\frac{Po+Po'}{2}.$$

The error in position of the principal point P of the perspective, considered in the last numerical example, will appear immediately if one wishes to determine the value of the focal length $=f$ by means of the abscissæ measured on the ground-glass plate (or on the negative).

We had found by measurement

$$x=46.05 \text{ mm.} \quad \text{and} \quad x'=75.40 \text{ mm.}$$

and the observed correpsonding angles of orientation were

$$\omega=10^\circ\ 44'\ 30'' \quad \text{and} \quad \omega'=17^\circ\ 18'\ 00''.$$

The twofold determination of f may be derived from the relations

$f=\dfrac{x}{\tan\omega}$	and	$f=\dfrac{x'}{\tan\omega'}$
$\log x=1.6632296$		$\log x'=1.8773713$
$\text{colog}\tan\omega=0.7219207$		$\text{colog}\tan\omega'=0.5065903$
$\log f=2.3851503$		$\log f=2.3839616$
$f=242.745$ mm.		$f=242.082$ mm.

Mean value for $f=242.41$ mm., differing but slightly from the value $f=242.33$ mm., previously obtained. Difference$=0.08$ mm.

Example No. V.—Giving the means for ascertaining the attainable degree of accuracy of the Italian phototopographic

method the following computation is of greater interest in a general way, as the panorama station was selected over a trigonometrical point of the Italian geodetic triangulation system, thus admitting a direct comparison between the elements of the perspective and the exact values of these same elements deduced from the data of the triangulation work.

In the panorama views, obtained on Sept. 21, 1884 (see Example No. II), vertically above the trigonometrical point known as Reale Accampamento there is one plate (P^5) which contains the pictures of two triangulation points, Punta Ruja and Gran Cima di Nomenon (the same points as previously mentioned). From the geodetic computations we take the following data:

Elevation of Punta Ruja (signal-mark)	$=3173.5$ m.
Elevation of P. di Nomenon (signal-mark)	$=3488.4$ m.
Elevation of camera horizon (Reale Accampamento)	$=2191.8$ m.
Distance: R. Accampamento–Ruja $=D$	$=5804.2$ m.
Distance: R. Accampamento–Nomenon $=D'$	$=5029.6$ m
Horizontal angle: $V=$ Ruja–Accampamento–Nomenon	$=13°\ 51'\ 04''.50$

It is desired to find (see Fig. 128, Plate LXIV):

(1) The focal length, f, approximately found by reading the scale attached to the objective tube $=244.50$ mm.

(2) The position of the principal point of view P which is located by the abscissæ x and x'.

The coordinates obtained by carefully executed measurements on the negative (the same as in the preceding) are for

Punta Ruja: $x=24.80$ mm.; $y=41.45$ mm.

Gran P. di Nomenon: $x'=34.05$ mm.; $y'=63.50$ mm.

Computation of the apparent difference in elevation:

Elevation of P. Ruja	= 3173.5 m.	Elevation of Nomon	= 3488.4 m.
Elevation of camera horizon	= 2191.8 m.	Elevation of camera horizon	= 2191.8 m.
True difference in level =	981.7 m.	True difference in level =	1296.6 m.
Correction for curvature and refraction	− 2.3	Correction for curvature and refraction	− 1.7 m.
Apparent difference of elevation	= 979.4 m. = L	Apparent difference of elevation	= 1294.9 m. = L'

Computation of $d = \frac{D}{L} \cdot y$.

$$\log D = 3.7637424$$
$$\log y = 8.6175245$$
$$\operatorname{colog} L = 7.0090399$$
$$\log d = 9.3903068$$
$$d = 245.644 \text{ mm.}$$

Computation of $d' = \frac{D'}{L'} \cdot y'$.

$$\log D' = 3.7015334$$
$$\log y' = 8.8027737$$
$$\operatorname{colog} L' = 6.8877638$$
$$\log d' = 9.3920709$$
$$d' = 246.644 \text{ mm.}$$

$$d + d' = 492.29 \text{ mm.}$$
$$d' - d = 1.00 \text{ mm.}$$

Computation of the angles γ and δ:

$$\tan \frac{\gamma - \delta}{2} = \frac{d' - d}{d + d'} \cot \frac{V}{2};$$

$$V = 13^\circ\ 51'\ 04''.50; \qquad \frac{V}{2} = 6^\circ\ 55'\ 32''.25.$$

$$\gamma + \delta = 180 - V = 166^\circ\ 08'\ 55''.50$$

$$\frac{\gamma + \delta}{2} = M = 83^\circ\ 04'\ 27''.75$$

$$\log (d' - d) = 7.0000000$$

$$\log \cot \frac{V}{2} = 0.9155404$$

$$\operatorname{colog} (d + d') = 0.3077790$$

$$\log \tan \frac{\gamma - \delta}{2} = 8.2233194$$

$$\frac{\gamma - \delta}{2} = 0^\circ\ 57'\ 29''.10 = N$$

$$M + N = 84^\circ\ 01'\ 56''.9 = \gamma$$
$$M - N = 82^\circ\ 06'\ 58''.7 = \delta$$

Computation of f:

$$f = d \sin \gamma.$$
$$\log d = 9.3903068$$
$$\log \sin \gamma = 9.9976402$$
$$\log f = 9.3879470$$
$$f = 0.244313 \text{ m.}$$

$$f = d' \sin \delta.$$
$$\log d' = 9.3920709$$
$$\log \sin \delta = 9.9958757$$
$$\log f = 9.3879466$$
$$f = 0.244313 \text{ m.}$$

Mean value for $f=244.31$ mm. is the same as obtained in numerical example No. 1.

Computation of the abscissæ x and x' (to check the position of the principal point P):

$x=f\tan\omega.$	$x'=f\tan\omega'.$
$\omega=90^\circ-\gamma=5^\circ\ 58'\ 03''.1$	$\omega'=90^\circ-\delta=7^\circ\ 53'\ 01''.3$
$\log f=\ 9.3879468$	$\log f=\ 9.3879468$
$\log\tan\omega=\ 9.0192462$	$\log\tan\omega'=\ 9.1413601$
$\log x=\ 8.4071930$	$\log x'=\ 8.5293069$
$x=25.54$ mm.	$x'=33.83$ mm.
Measured $x=24.80$ mm.	Measured $x'=34.05$ mm.
Diff.$=\ 0.74$ mm.	Diff. $=\ 0.22$ mm.

The mean difference$=0.48$ mm.$=$error in the position of the principal point P of the perspective P^5 (Accampamento panorama). The true point P^5 is 0.5 mm. to the right of P^5, Fig. 122, Plate LXI, and the vertical line ff' (the principal line) on the plate, Fig. 128, Plate LXIV, should be moved towards Punta di Nomenon (image) 0.5 mm.

The preceding five numerical examples may well serve to elucidate the relations between the elements of the photographic perspectives and their corresponding parts of the terrene, as well as to give the means for forming a correct idea of the degree of accuracy, attainable in the Italian photographic surveying method.

In practical work it would be too time consuming to make such computations (with the necessary minute and careful graphical measurements) for every negative, or even for every set of panorama views.

If the phototheodolite has been carefully planned and is well constructed, the optical axis should always remain perpendicular to the image plane, hence be horizontal when the latter is vertical. The value f for any (or for all) panorama views, obtained with the same objective and with the same constant focal length (obtained under the same reading of the scale attached to the objective tube), may be computed from the formula

$$f=\frac{x^m}{\tan 18^\circ}.$$

In the panorama set of Accampamento Reale station we had one plate, P', Fig. 122, Plate LXI, containing the image of the signal at Punta Cian del Lei, bisected by the principal line, VP', and another plate, P^5, containing the images of two other points, Punta Nomenon and Punta Ruja.

The horizontal shiftings in azimuth

$$P'VP^2, \quad P^2VP^3, \quad P^3VP^4 \ldots,$$

representing the horizontal swings in azimuth of the camera for each successive exposure, are all alike, each being $=36°$, and the horizontal angles

$$P'Vm, \quad mVP^2, \quad P^2Vm' \ldots$$

will each be $=18°$.

The horizontal angle, included between the principal lines VP' and VP^5 (between the horizontal direction to the reference point P. Cian del Lei and the principal line of perspective No. 5) will be $=4 \times 36° = 144°$ (Fig. 122, Plate LXI).

We find in the trigonometrical records, or from direct observation at the station Accampamento Reale:

Horizontal angle: Cian del Lei–Accampamento–Nomenon $= 135° \; 58' \; 23''.25$

Horizontal angle: Nomenon–Accampamento–Ruja $= 13° \; 51' \; 04''.5$

Hence the horizontal angles of orientation for the fifth plate:

$$\begin{aligned} \measuredangle\, \omega' &= (P^5 - V - \text{Nomenon}) &&= 8° \; 01' \; 36''.75 \\ \measuredangle\, \omega &= (\text{Nomenon} - V - \text{Ruja}) - \omega' &&= 5° \; 49' \; 27''.75 \\ \hline & && \ 13° \; 51' \; 04''.50 \end{aligned}$$

In the computation for the abscissæ x and x' under Example No. V we had found

$$\omega' = 90° - \delta = 7° \; 53' \; 01''.3$$

and

$$\omega = 90° - \gamma = 5° \; 58' \; 03''.1.$$

The differences between these values for ω is $=08' \ 35''.35$ and for $\omega' = 08' \ 35''.45$, or the difference in the mean value of ω and ω' is expressed by

$$\varDelta\omega = \mp 8' \ 35''.40,$$

being about the same error in azimuth of the principal point P that had been found for the panorama obtained from the station Punta Percia with the same instrument (considered under Example No. IV, where we obtained $\varDelta\omega = \pm 8' \ 28''.9$). This error, $\varDelta\omega = \pm 8' \ 35''.40$, corresponds to a horizontal linear displacement, $\varDelta x$, of the principal point P of the photographic perspective:

$$\varDelta x = \mp 0.610 \text{ mm.}$$

5. Application of Franz Hafferl's Method for Finding the Focal-length Value of a Photographic Perspective from the Abscissæ of two Pictured Terrene Points.

When the horizontal distances, D and D', are great compared with the differences in elevation between the pictured points under consideration and the camera station, the ordinates, y and y', will be rather short and the accurate measurement of their lengths will be difficult.

In such case it may become advisable to determine the value of the focal length f by means of the abscissæ, x and x', of the pictured terrene points. To do this L. P. Paganini uses the following method, suggested by Franz Hafferl of Vienna.

We have with reference to Fig. 129, Plate LXIV:

OO' = horizon line of photographic perspective;
Vs and Vs' = horizontal directions from the camera station V to the pictured points s and s';
VP = perpendicular to the horizon line OO'.

It is desired to find the length value for f.

Describe a circle through the three points V, s, and s', the center of which may be at C. The angle sCs' is double the angle sVs' and the perpendicular CM to the line ss' will divide this line and also the center angle sCs' into two equal parts; hence

$$\measuredangle sCM = \measuredangle s'CM = \measuredangle sVs'.$$

If R be the radius of the circle described through the three points s, s', and V, we will have, from the triangle sMC, the following relation:

$$sC = R = \frac{SM}{\sin V} = \frac{x+x'}{2} \cdot \frac{1}{\sin V}; \quad \text{as} \quad SM = \frac{x+x'}{2}.$$

After having drawn the diameter mn parallel to ss' we find

$$f = VP = VA + AP.$$

VA being vertical to mn it will be the middle proportional to mA and An:

$$mA : AV = AV : An,$$
$$mA \cdot An = (AV)^2.$$

We can replace mA by $(mC - AC) = R - \frac{x'-x}{2}$; $AC = SM - SP$;

and as $$An = nC + AC = R + \frac{x'-x}{2},$$

we will have $$AV = \sqrt{\left(R - \frac{x'-x}{2}\right)\left(R + \frac{x'-x}{2}\right)}$$

and finally $$AP = CM = SM \cot V = \frac{x'+x}{2} \cot \cdot V.$$

Example No. VI.—Determination of the value f for a plate by means of the abscissæ of two pictured points.

From the data derived from the computation in Example No. IV we find

$$V = 28° \ 02' \ 30''$$

$$x = 46.05 \text{ mm.} \qquad \text{and} \qquad x' = 75.40 \text{ mm.}$$

$$x + x' = 121.45 \text{ mm.} \qquad x' - x = 29.35 \text{ mm.}$$

$$\frac{x+x'}{2} = 60.725 \text{ mm.} \qquad \frac{x'-x}{2} = 14.675 \text{ mm.}$$

Computation of $R = \dfrac{x+x'}{2} \cdot \dfrac{1}{\sin V}$:

$$\log \frac{x+x'}{2} = 1.7833675$$

$$\text{colog} \sin V = 0.3277972$$

$$\log R = 2.1111647$$

$$R = 129.171 \text{ mm.}$$

Computation of $VA = \sqrt{\left(R + \dfrac{x'-x}{2}\right)\left(R - \dfrac{x'-x}{2}\right)}$:

$$R + \frac{x'-x}{2} = 143.846 \text{ mm.}$$

$$R - \frac{x'-x}{2} = 114.496 \text{ mm.}$$

$$\log \left(R + \frac{x'-x}{2}\right) = 2.1578978$$

$$\log \left(R - \frac{x'-x}{2}\right) = 2.0587903$$

$$\log \overline{VA}^2 = 4.2166881$$

$$\log VA = 2.1083440$$

$$VA = 128.335 \text{ mm.}$$

Computation of $PA = \frac{x+x'}{2} \cot V$:

$$\log \frac{x+x'}{2} = 1.7833675$$
$$\log \cot V = 0.2735641$$

$$\log PA = 2.0569316$$
$$PA = 114.007 \text{ mm.}$$

Hence $$f = VA + PA = 242.342 \text{ mm.},$$

which compares very closely with

$$f = 242.332 \text{ mm.},$$

obtained under numerical Example No. IV.

In practical work, like the great Italian topographic survey, it would take too much time and labor to determine the focal length (f), after the method just shown, for each perspective, or even for each panorama set. If there is no reason for doubt that the optical axis of the camera intersects the picture plane at right angles (as it does for the Italian phototheodolite with a sufficient degree of precision) it will be more simple to determine the value f for an entire panorama set (and also for all subsequent panoramas that may be executed with the same objective, and with the same focal length, which may be verified at each exposure) by simply checking the scale-reading on the objective tube, which should remain the same for all pictures. Under this supposition the focal length is computed in the following manner:

Since the azimuthal swings of the camera after each exposure,

$$P'VP^2, \quad P^2VP^3, \quad P^3VP^4 \ldots,$$

are all alike, and each being equal to 36° (Fig. 122, Plate LXI), the angles

$$P'Vm, \quad mVP^2, \quad P^2Vm' \ldots$$

will each be $=18°$. If x^m denotes the maximum length of the abscissæ of the plates then

$$x^m = P'm = mP^2 = P^2m' = \ldots = f \tan 18°,$$

hence
$$f = \frac{x^m}{\tan 18°}.$$

In the preceding (page 93) it has been stated that two adjoining negatives of a panorama set have a vertical marginal strip of the pictured terrene in common, and the width of this strip may be expressed in arc by the angle pVq (Fig. 122, Plate LXI).

If the negatives are sufficiently clear (showing a good definition) it will be an easy matter to locate a point m, either on the negative or on the photographic print, that may be identified on both overlapping strips pq (Fig. 122, Plate LXI) of two adjoining plates P' and P^2, which will be on or near the horizon line OO', and distant from the principal line ff' of plate P' by mP', and distant from the principal line of plate P^2 by mP^2, mP' being $=mP^2$.

If we now select such points m', m'', m''' . . . , that can be readily identified upon two adjoining perspectives,

$$P^2 \text{ and } P^3, \quad P^3 \text{ and } P^4, \quad P^4 \text{ and } P^5 \ldots,$$

we will obtain ten values for m for the entire set, and the focal length, f, for the panorama may be determined by means of the preceding formula,

$$f = \frac{x^m}{\tan 18°},$$

where x^m is the arithmetical mean of the ten greatest abscissæ

$$P'm, \quad mP^2, \quad P^2m' \ldots .$$

Example No. VII.—By means of ten negatives of a panorama station, obtained with Paganini's phototheodolite, described in "La Fototopografia in Italia," the following values were found for the distances x^m:

$$\left.\begin{array}{llll} x^m & \text{for } P^1 - P^2 & = 77.10 & \text{mm.} \\ x^m & \text{“ } P^2 - P^3 & = 77.15 & \text{“} \\ x^m & \text{“ } P^3 - P^4 & = 77.00 & \text{“} \\ x^m & \text{“ } P^4 - P^5 & = 77.40 & \text{“} \\ x^m & \text{“ } P^5 - P^6 & = 77.40 & \text{“} \\ x^m & \text{“ } P^6 - P^7 & = 77.20 & \text{“} \\ x^m & \text{“ } P^9 - P^{10} & = 77.40 & \text{“} \\ x^m & \text{“ } P^{10} - P^1 & = 76.90 & \text{“} \end{array}\right\} x^m = 77.194 \text{ mm.} = \text{mean value.}$$

$$\begin{aligned} \log 77.194 &= 1.8875835 \\ \text{colog tan } 18^\circ &= 0.4882240 \\ \hline \log f &= 2.3758075 \\ f &= 237.6 \text{ mm.} \end{aligned}$$

The above values were obtained by using the negative plates and reading the measurements scaled off (by means of dividers) on the graduated rulers of the graphical instruments (“ iconometers ”) of the Royal Military Geographical Institute.

Using the positives (albumen prints) of the same panorama the following results were obtained:

$$\left.\begin{array}{llll} x^m & \text{for } P^1 - P^2 & = 76.25 & \text{mm.} \\ x^m & \text{“ } P^2 - P^3 & = 76.20 & \text{“} \\ x^m & \text{“ } P^3 - P^4 & = 76.10 & \text{“} \\ x^m & \text{“ } P^9 - P^{10} & = 76.70 & \text{“} \\ x^m & \text{“ } P^{10} - P^1 & = 76.00 & \text{“} \end{array}\right\} x^m = 76.25 \text{ mm.} = \text{mean value.}$$

$$\begin{aligned} \log 76.25 &= 1.8822398 \\ \text{colog tan } 18^\circ &= 0.4882240 \\ \hline \log f &= 2.3704628 \\ f &= 234.67 \text{ mm.} = 234.7 \text{ mm.} \end{aligned}$$

$$\begin{aligned} &\text{The negatives gave } x^m = 77.19 \text{ mm.} \\ &\text{The positives gave } x^m = 76.25 \text{ mm.} \\ \hline &\qquad\qquad \text{Diff.} = \ \ 0.94 \text{ mm.} \end{aligned}$$

The evident contraction of the greatest abscissa—amounting to very nearly one millimeter on the prints—is due to the shrink-

age in the 24×18 cm. albumen paper. Whenever "positives" (prints) are used in the iconometric map construction, this shrinkage should be ascertained and taken into account. Of course, the elements of the "contracted" photographic perspectives are now substituted for those of the glass negatives.

6. Supplement.

I. Forms Showing Arrangements of Field Records for Panorama Views.

Station	on Punta Bivula (trigon. pt.), on the ridge between the valleys of the Valsavaranche and Rhêmes.
Date,	September 18, 1884.

Orientation of the Panorama.	Perspectives belonging to the Panorama.	Directions to the Principal Points of View.	Focal Distance.	Remarks.
				Time of exposure:
Punta Gran Paradiso, 78° 27′ 00″	P^1	78° 27′	244.5 mm. Steinheil's objective "antiplanat"	10^s with smallest diaphragm, No. 7
	P^2	114 27		10^s
	P^3	150 27		9^s
	P^4	186 27		12^s
	P^5	222 27		9^s
Punta della Grivola, 123° 47′ 00″	P^6	258 27		10^s Fine weather
	P^7	294 27		9^s
	P^8	330 27		10^s
	P^9	6 27		10^s
	P^{10}	42 27		10^s

Directions and Vertical Angles of the Trigonometrical Points.	Computation of Elevation of Station and Elevation of Line of Horizon.
	Station on partly removed signal. Elevation of instrument = 2.30 m. Geodetic point, elevation = 3413.69 m. Elevation of lines of horizon of the panorama = 3415.99 = 3416 m.

(The adjoining page of the record book may be utilized for topographic sketches from station, for detailed remarks, names of roads, etc.)

Station	on Punta Percia, on ridge between the valleys of the Valsavaranche and the Rhêmes.
Date,	September 19, 1884.

Orientation of the Panorama.	Perspectives belonging to the Panorama.	Directions to the Principal Points of View.	Focal Distance.	Remarks.
Punta dell' Erbetet, 282° 04′ 00″	P^1	170° 00′	244.5 mm.	Time of exposure: 6s
	P^2	206 00	Steinheil's objective "antiplanat"	7s
	P^3	242 00		8s
	P^4	278 00		9s Shorter exposure than before on account of the great reflection from surrounding glacier.
	P^5	314 00		10s
	P^6	350 00		8s
	P^7	26 00		9s
	P^8	62 00		9s Diaphragm No. 7
	P^9	98 00		10s Fine weather
	P^{10}	184 00		7s

Directions and Vertical Angles to the Surrounding Trigonometrical Points.				Computation of Elevation of Station and Elevation of Line of Horizon.	
Cima di Breuil	220°	54′	00″	Elevation of Invergnan	= 3607.72 m.
Elevation	1	33	00	Diff. of elev. + corr.	= 406.15
Punta dell' Erbetet	282	04	10		3201.57
Elevation	3	36	30	Elevation of Nomenon	= 3488.42
				Diff. of elev. + corr.	= 284.94
Cima di Nomenon	222	42	00		3202.48
Elevation	1	38	30	Elevation of Toss	= 3302.24
				Diff. of elev. + corr.	= 99.84
Cima di Rouletta	0	44	30		3202.40
Elevation	3	11	30	Elevation of Breuil	= 3454.62
				Diff. of elev. + corr.	= 252.64
Punta dell' Invergnan	80	07	00		3201.98
Elevation	3	42	00	Elevation of Rouletta	= 3384.10
				Diff. of elev. + corr.	= 182.28
Cima di Toss	34	11	30		3201.82
Elevation	0	30	30	Elev. of line of horizon	= 3202.30

II. FORM USED FOR RECORDING THE ELEVATIONS OF SECONDARY POINTS OF THE PANORAMA VIEWS.

Names or Numbers of Points.	Stations whence They were Derived.	Elevations of Stations.	Difference of Elevations.	Elevation of Point.	Remarks.

D. General Arithmetical Method for Finding the Plotted Positions of Terrene Points when Pictured on Vertically Exposed Picture Planes.

With reference to Fig. 43, Plate XXIV, we have

S and S' = the two camera stations;

MN and $M'N'$ = two photographic perspectives obtained from S and S' respectively;

a and a' = two pictures of a point A;

$f = SP = S'P'$ = constant focal length for both pictures or plates;

$D = S_0A_0$ = horizontal distance from S to A;

$D' = S_0'A_0$ = horizontal distance from S' to A;

$d = S_0a_0$;

$d' = S_0'a_0'$;

$B = S_0S_0'$ = horizontal distance between the two stations S and S', the elevation of A above the horizon plane of the station $S = H$ and above the horizon plane of the station $S' = H'$.

Finally, the horizontal angles included between B and the principal planes that pass through the two stations S and $S' = \alpha_0$ and α_0' respectively.

If we refer the pictured points to the principal point P of the photographic perspective by means of the rectangular sys-

tem of coordinates formed by the principal and horizon lines (ff' and OO') the coordinates of a on MN will be

$$aa' = y, \qquad a'P = x,$$

and those of a' on $M'N'$ will be

$$a'a_1' = y', \qquad a_1'P' = x'.$$

If the camera is in perfect adjustment, if the base line B has been measured in the field, and if the angles α_0 and α_0' have been observed, we know the values of

$$B,\ \alpha_0,\ \alpha_0',\ f,\ x,\ x',\ y, \text{ and } y'$$

(the coordinates are measued on the negatives MN and $M'N'$) and we can now compute:

(1) The horizontal angle γ (or γ') included between the principal ray SP (or $S'P'$) and the horizontal direction Sa' (or $S'a_1'$) to any point A from the equation

$$\tan \gamma = \frac{x}{f} \quad \left(\text{or} \quad \tan \gamma' = \frac{x'}{f}\right).$$

(2) The vertical angle β (or β') included between the plane of horizon for the station S (or S') and the line of direction Sa (or $S'a'$) to any point A from the equation

$$\tan \beta = \frac{y}{d} \quad \left(\text{or} \quad \tan \beta' = \frac{y'}{d'}\right),$$

and as

$$d = \sqrt{f^2 + x^2} \quad (\text{or} \quad d' = \sqrt{f^2 + (x')^2}),$$

we may write

$$\tan \beta = \frac{y}{\sqrt{f^2 + x^2}} \quad \left(\text{or} \quad \tan \beta' = \frac{y'}{\sqrt{f^2 + (x')^2}}\right).$$

Of the triangle $S_0A_0S_0'$ we know the side $S_0S_0'=B$ and the angles γ, α_0, γ', and α_0'; hence

$$\frac{B}{D}=\frac{\sin(\gamma'+\alpha_0')}{\sin[180^\circ-(\gamma+\alpha_0+\gamma'+\alpha_0')]}=\frac{\sin(\gamma'+\alpha_0')}{\sin(\gamma+\alpha_0+\gamma'+\alpha_0')};$$

whence

$$D=S_0A_0=\frac{B\cdot\sin(\gamma'+\alpha_0')}{\sin(\gamma+\alpha_0+\gamma'+\alpha_0')}$$

$$\left(\text{or}\quad D'=S_0'A_0=\frac{B\sin(\gamma+\alpha_0)}{\sin(\gamma+\alpha_0+\gamma'+\alpha_0')}\right).$$

We can now compute from

$$\tan\beta=\frac{H}{D},$$

the difference in elevation between A and S (or S'),

$$H=D\tan\beta\quad(\text{or}\quad H'=D'\tan\beta').$$

E. General Arithmetical Method for Finding the Plotted Positions of Terrene Points when Pictured on Inclined Picture Planes.

For inclined picture planes we will have to take the angles of inclination of the plates into consideration. Under angle of inclination of a plate we understand that angle which is included between the optical axis of the inclined camera and the horizon plane of the camera station (second nodal point).

Referring to Fig. 38, Plate XXII, and Fig. 44, Plate XXV, we have

α = horizontal angle included between the principal plane and the vertical plane passing through the station S and the point A, pictured as a;

β = angle of elevation of the point A;

γ = angle of inclination of the photographic plate MN;

δ = complement of $\gamma = 180° - \gamma$;
OO' = horizon line when MN is vertical (OO' is permanently marked on the camera);
P = principal point for the vertically exposed plate;
$P\pi = y$ = ordinate of a, Fig. 44, Plate XXV;
$a\pi = x$ = abscissa of a, very nearly $= a'P'$, Fig. 44, Plate XXV;
Σ = vanishing point ("kernel point") for all vertical lines pictured on MN.

From inspection of Fig. 44, Plate XXV, we find directly

$$\tan\beta = \frac{a\alpha'}{S\alpha'} = \frac{\pi\pi'}{S\alpha'} = \frac{\pi\rho}{S\alpha'} = \frac{P\rho - P\pi}{\sqrt{x^2 + (S\pi')^2}} = \frac{y\cos\gamma - f\sin\gamma}{\sqrt{x^2 + (S\pi + \pi\pi')^2}}$$

$$= \frac{y\cos\gamma + f\sin\gamma}{\sqrt{x^2 + (S\pi + \rho\pi)^2}} = \frac{y\cos\gamma - f\sin\gamma}{\sqrt{x^2 + (f\cos\gamma + y\sin\gamma)^2}},$$

and

$$\tan\alpha = \frac{\alpha'\pi'}{S\pi'} = \frac{x}{S\pi + \rho\pi} = \frac{x}{f\cos\gamma + y\sin\gamma}.$$

For the vertically exposed plates we had found

$$\tan\beta = \frac{y}{\sqrt{x^2 + f^2}} \quad \text{and} \quad \tan\alpha = \frac{x}{f}.$$

The preceding formulas for the inclined plates will assume the form of the latter if the angle of inclination γ is reduced to O, as $\sin\gamma$ will then become equal to O and $\cos\gamma$ equal to 1.

After the values for α and β (or α' and β') have been computed the value for $S_0A_0 = D$ (or $S_0'A_0 = D'$) and for $AA' = H$ (or $AA'' = H'$) may be obtained as follows:

Referring to Fig. 38, Plate XXII, we find

$$\frac{D}{B} = \frac{\sin(\varepsilon' - \alpha')}{\sin[180° - (\alpha + \varepsilon + \varepsilon' - \alpha')]},$$

hence

$$D = \frac{B \cdot \sin(\varepsilon' - \alpha')}{\sin(\alpha + \varepsilon + \varepsilon' - \alpha')},$$

and from
$$\frac{H}{D}=\tan\beta$$

we obtain

$$H=D\tan\beta=D\cdot\frac{\gamma\cos\gamma-f\sin\gamma}{\sqrt{x^2+(f\cos\gamma+y\sin\gamma)^2}}.$$

If an ordinary surveying camera with constant focal length is used, and it should become desirable to expose a plate in an inclined plane, the complement δ of the angle of inclination γ of the optical axis may be more readily (but only approximately) determined than γ by carefully measuring the distances AD, Fig. 45, Plate XXV (in the direction of the line of a suspended plumb-bob), and DB, AB, being parallel with the photographic plate.

F. General Analytical Determination of the Elements of a Photographic Perspective.

When in addition to the photographs other data—obtained by the necessary instrumental measurements—are given for a graphical determination of the focal lengths of the pictures, their horizon lines and their principal lines, then these elements may also be determined analytically.

A picture MN, containing the images a, b, and c of three known points A, B, and C, may be given and the position of the camera station (whence this picture was obtained) may be known with reference to the three plotted points A', B', and C', Fig. 46, Plate XXVI.

To orient the picture trace (or the ground line) gg' with reference to the plotted station S' and plotted points A', B', and C' the latter are preferably referred to a rectangular system of coordinates ($S'Y$ and $S'X$, Fig. 46, Plate XXVI) having the plotted station S' as the origin. To simplify matters one of the axes of the system may be laid through one of the plotted

points. In Fig. 46, Plate XXVI, the axis of abscissæ $S'X$ passes through the point c'.

The coordinates of the points A', B', and C', measured on the plotting-sheet, may be

$$X_1 Y_1,\ X_2 Y_2, \text{ and } X_3 \text{ respectively.}$$

The coordinates of the orthogonal projections (on the picture trace gg') of the corresponding points pictured on the photograph MN and located upon the radials $S'A'$, $S'B'$, and $S'C'$ may be designated by

$$x_{\mathrm{I}} y_{\mathrm{I}},\ x_{\mathrm{II}} y_{\mathrm{II}}, \text{ and } x_{\mathrm{III}} \text{ respectively.}$$

The horizontal distances measured on the photographic plate between a and b, between b and c, and between a and c (the same as those measured on the picture trace between a' and b', between b' and c', between a' and c') may be designated by

$$m^{\mathrm{I}},\ m^{\mathrm{II}}, \text{ and } m^{\mathrm{III}} \text{ respectively.}$$

From an inspection of Fig. 46, Plate XXVI, it will be evident that

$$(1)\ y_{\mathrm{I}} : x_{\mathrm{I}} = Y_1 : X_1;$$
$$(2)\ y_{\mathrm{II}} : x_{\mathrm{II}} = Y_2 : X_2;$$
$$(3)\ y_{\mathrm{I}} : y_{\mathrm{II}} = m^{\mathrm{III}} : m^{\mathrm{II}};$$
$$(4)\ (x_{\mathrm{III}} - x_{\mathrm{I}}) : (x_{\mathrm{II}} - x_1) = m^{\mathrm{III}} : m^{\mathrm{I}};$$
$$(5)\ (x_{\mathrm{III}} - x_{\mathrm{I}})^2 + (y_{\mathrm{I}})^2 = (m^{\mathrm{III}})^2.$$

From these five equations the five unknown quantities of x_{I}, y_{I}, x_{II}, y_{II}, and x_{III}—the coordinates of the points to be located—may be computed.

From the area of the triangle $S'a'c'$,

$$\frac{y_{\mathrm{I}} \cdot x_{\mathrm{III}}}{2} = f\frac{m^{\mathrm{III}}}{2},$$

we find the focal length

$$f=\frac{y_{\mathrm{I}} \cdot x_{\mathrm{III}}}{m^{\mathrm{III}}}.$$

The angle of orientation γ, included between the principal ray $S'P'$ and the base line $S'C'$, may be derived from the equation

$$\cos \gamma=\frac{f}{x_{\mathrm{III}}} \quad \text{or} \quad =\frac{y_{\mathrm{I}}}{m^{\mathrm{III}}}.$$

The principal point P' may be located upon gg' by laying off on the picture trace gg' from c' the length,

$$P'c'=x_{\mathrm{III}} \sin \gamma.$$

The differences in elevation between the station S and the three points A, B, and C being known it will be an easy matter to draw the horizon line upon the photograph.

II. Graphical Iconometrical Plotting Methods.

A. Col. A. Laussedat's Method (French Method).

Col. Laussedat's methods of constructing topographic maps from (photographic) perspective views of the terrene having been widely published, they form the groundwork for all subsequent work in this field. They are chiefly of a graphical character and in harmony with the laws of perspective. Col. Laussedat considers two general cases in reconnoitering expeditions where phototopographic methods may be applied with advantage:

First. The observer may remain sufficiently long in one locality to make a survey on a large scale, say 1:20000 and even larger for special purposes.

Second. The explorer moves rapidly from place to place, gathering only the most necessary data on his itinerary to enable him to plot the topography of the traversed country as a "running survey" on a small scale—say, 1:50000 or smaller—preserving and representing only the principal topographic features met with on the track survey.

In the first-mentioned case the explorer will measure one or more base lines with as great an accuracy as the means and time at his disposal will admit. He will cover the area to be mapped with a system of triangles connected with the base lines, and inasmuch as the triangulation stations will also be occupied with the surveying camera the scheme should be laid out with due reference to the subsequent iconometric plotting of the topographic features.

When applying the ordinary surveying methods the triangulation scheme would probably be laid out with a view toward covering as large a territory as possible with each triangle, occupying the smallest possible number of intervisible points.

With the application of photography, however, the conditions become somewhat changed. Every topographic feature that is to be plotted iconometrically should be seen from two or more camera stations, and as each camera station is to be connected with the triangulation system, either directly or indirectly, the number of triangulation points should be a relatively large one. Often it will not be desirable that the highest peaks trigonometrically laid down on the map should be occupied with the camera, especially when fogs prevail in the higher altitudes, and when other camera stations would answer the requirements just as well.

Regarding the second case, where the explorer follows a certain route without making side excursions and never stopping longer in one place than is absolutely necessary for his observations, the phototopographic method becomes even more valuable than in the first case, particularly when traversing open and

broken country. For this kind of topographic reconnaissance it may well be said that the photographic method surpasses all other surveying methods regarding the amount of data which may be collected in the field in a limited time period.

All topographic operations and instruments serve to measure distances and vertical and horizontal angles. A photographic perspective of which the elements are known will give all the data needed to determine the vertical and horizontal angles of lines of direction drawn from the point of view to all points pictured on the photograph.

The points A and B shown on the plate MN, Fig. 47, Plate XXVI, may represent the pictures of two mountain peaks. The points marked a and b will be their projections upon the horizon line HH'. The angle $aSb=\alpha$ will be the horizontal angle of the lines of direction SA and SB if S is the point of view on the distance line SP.

The vertical angles β and γ may be shown in horizontal plan by revolving the vertical planes passing through SA and SB about the lines Sa and Sb, respectively, until they coincide with the horizon plane HH', when

$$a(A)=aA,$$
$$(A)aS=AaS=90^\circ,$$
$$\beta=ASa=(A)Sa=(\beta).$$

The vertical angles β and γ may now be measured in horizontal plan as (β) and (γ).

To indicate in a general way Laussedat's method of iconometric plotting and to show how the plotted features of the terrene may be obtained from the photographs we will refer to Figs. 48 and 49, Plate XXVII, where A, B, and C represent three camera stations (plotted in horizontal plan, Fig. 48), whence three perspectives I, II, and III, Fig. 49, of the same knoll D may have been obtained. The traces of these three pictures on the plotting-sheet may be H_AH_A, H_BH_B, and H_CH_C. All three photographs having been taken with the same instrument of constant

focal length, the distance lines $P_A A$, $P_B B$, and $P_C C$ will be equally long.

1. Orientation of the Picture Traces on the Plotting-sheet.

The three stations A, B, and C are plotted either as parts of the triangulation system or by measuring the base line AB on the ground and observing the horizontal angles CAB and CBA, when the sides AC and BC may be found graphically or by computation and the triangle ABC be plotted upon the working-plan.

Horizontal angles or directions to D having also been observed from A, B, and C, its position with reference to A, B, and C may also be plotted.

To orient or plot the three picture traces we must know the horizontal angles α_A, α_B, and α_C, which are generally observed for each picture by means of the horizontal circle attached to Laussedat's phototheodolite.

These angles are plotted from A, B, and C on the lines AD, BD, and CD with reference to the position of D on the photographs, whether to right or left of the principal line VV. The constant focal length $= f$ of the three negatives I, II, and III is now laid off on the radials AP_A, BP_B, and CP_C. Perpendiculars erected in P_A, P_B, and P_C to the lines AP_A, BP_B, and CP_C respectively, will represent the picture traces H_AH_A, H_BH_B, and H_CH_C. The abscissæ P_Ad_A, P_Bd_B, and P_Cd_C, measured on the negatives I, II, and III, should be made equal to the distances P_Ad_A, P_Bd_B, and P_Cd_C on the picture traces.

The point D is termed a "reference point," and every picture that is to be used for iconometric plotting should contain the image of at least one such reference point of known position in both the horizontal and vertical sense.

2. Locating Points on the Plotting-sheet that have been Identified on Several Photographs.

After the picture traces have been oriented any (other) point T of the terrene shown on two or more pictures may readily

be plotted without requiring additional instrumental measurements in the field.

To locate the plotted position of the point T, Fig. 48, Plate XXVII, shown as t_A and t_C on two pictures I and III, Fig. 49, Plate XXVII, the abscissæ $P_A t_A$ and $P_C t_C$ are laid off on the picture traces $H_A H_A'$ and $H_C H_C'$, respectively, from P_A and P_C, Fig. 48, and on the side of P corresponding with the position of the image t with reference to the principal line VV, Fig. 49, Plate XXVII.

Lines drawn from A and C, Fig. 48, through t_A and t_C will represent horizontal directions to T from the stations A and C; their intersection at T will locate the position of the tree in horizontal plan.

3. The Iconometric Determination of Elevations of Pictured Terrene Points.

The horizon line HH' of a perspective view, Fig. 47, Plate XXVI, being the intersection of the horizon plane with the vertical picture plane, will intersect points in the picture which in nature have the same elevation as the optical axis SP of the camera. All pictured points falling above the horizon line are higher and all points falling below the horizon line are lower in elevation than the point of view S.

The distances Sa and SA, Fig. 50, Plate XXVII, are measured on the plotting-sheet and the ordinate (Aa, Fig. 47, Plate XXVI) of the pictured point a (its distance from the horizon line) is taken from the negative. Perpendiculars to SA are then erected in a and A (on the plotting-sheet, Fig. 50, Plate XXVII), and the one in a is made equal to the ordinate (Aa, Fig. 47, Plate XXVI) of the pictured point $= a(a)$, Fig. 50, Plate XXVII.

If we now draw the line $S(a)$ to its intersection with the perpendicular to SA in A, the triangle $Sa(a)$ and $S(A)A$ will be similar and the angle $AS(A)$ will represent the vertical angle of the visual ray from S to A, revolved about SA into the plane

of the horizon. From the similar triangles $Sa(a)$ and $SA(A)$ we derive the proportional equation

$$A(A):SA = a(a):Sa,$$

whence

$$A(A) = \frac{\overline{a(a)} \cdot \overline{SA}}{\overline{Sa}}.$$

$a(a)$ is measured on the negative; SA and Sa are taken from the plotting-sheet. $A(A)$ measured on the plotting-scale will give the difference in elevation between S and A.

In practical work the elevations of the camera stations are known and by adding the height of the instrument including the value for $A(A)$ to the elevation of the camera station the absolute elevation of the geodetic point A is found, which, however, is still to be corrected for curvature and refraction.

A second value for the elevation of the geodetic point A is found in the same manner from another negative containing an image of A and obtained from another station. The mean of several such determinations is adopted for the final value for the height of A.

4. Drawing the Plan Including Horizontal Contours.

After some little practice, points pictured on different negatives but representing identical geodetic points will readily be identified by the observer and he will select characteristic points to reproduce the watercourses, water-sheds, roads, shore lines, etc., on the plotting-sheet.

After these principal guide lines are well located on the chart the buildings, outlines of woods, marshes, etc., are plotted, including everything that is to be shown on the finished map.

Enough points must be plotted iconometrically to form a good control for a correct delineation of the relief. Should the number of points determined on the plan be sufficient only to

give an adequate control for the delineation in the horizontal sense, additional points should be plotted from the photographs to obtain an equally good control of the terrene in the vertical sense.

The planimetric work completed, elevations of as many of the plotted points as seem necessary are determined and inscribed on the chart. Horizontal equidistant contours may then be drawn by interpolation to harmonize with the elevations suffixed to the points of control on the chart, conforming the courses of the contours between the determined points to the configuration of the terrene as it is shown on the panorama views.

It cannot be denied that a certain amount of study and practical application are requisite to enable the iconometric draughtsman to interpret forms correctly when shown in perspective. Yet it should also be admitted that such translation or conversion of the configuration of the terrene into horizontal projection may be accomplished far more accurately at one's leisure in the office by means of geometrically correct perspectives than could be accomplished by sketching in the field.

When topographic features as seen from one direction are sketched by the plane-tabler, their forms will often be found to have been misconceived when they are again seen from another point of view. Of course, forms sketched on the plane-table sheet may then be corrected, in a measure at least, but many details are sketched that will not be seen again from other stations, and even those that are again observed from other stations may not be modified to conform with their true shapes unless the original station whence they were first seen and sketched could again be occupied to verify the suggested changes, and, generally speaking, topographers regard a second occupation of a station with little favor, considering it too great a loss of time, retarding progress and considerably increasing the cost of the work.

In iconometric plotting, however, it would be an easy matter

to refer back to the panorama views obtained from some other station, and the plotting of topographic details should not be attempted without having first made a careful study of (and a close comparison between) the various pictures representing identical areas but seen from different points of view.

B. Dr. A. Meydenbaur's Method (German Method).

The pantoscopic lens (made by E. Bush in Rathenow, Prussia) of Dr. Meydenbaur's surveying camera commands an angle of about 100°. By excluding the external rays of the effective field of these lenses by means of diaphragms (within the camera) pictures are obtained subtending a horizontal angle of but 60° (irrespective of the 5 mm. wide margins with which two adjoining plates lap over each other) requiring six plates for a complete panorama.

After the camera has been adjusted over a station the panorama is photographed by exposing six plates in succession, each successive turn of the camera in azimuth covering an angle of 60°, two adjoining plates lapping over each other by a margin of 3° in arc, Fig. 51, Plate XXVIII. These common margins, containing identical sections of the panorama view, may well serve to find the value for the focal length of the negatives.

From the panorama set of six plates exposed from one station objects or geodetic points may be selected on the middle lines of the common margins of adjoining plates that must be equidistant from the principal lines of adjoining plates.

1. Determination of the Focal-length Value for the Photographic Perspective.

After having selected a series of such reciprocal points, using a magnifier of low power if needed, on all six plates, we shall have twelve determinations (represented by the length l) of the positions of the principal line and the greatest discrepancy between any two values should not exceed 0.2 mm. if the instrument is well adjusted. The sum $2l$ of two such distances

represents the effective length of one picture, or the length of one side of a regular hexagon, with an inscribed circle of the radius equal to the constant focal length $=f$ of the negatives. The value for the focal length may be found graphically or it may be computed from the formula

$$f=\frac{l}{\tan 30^\circ}.$$

When "positive prints" are to be used in the iconometric map construction this focal length often will have to be changed to correspond with changes that may have taken place in the dimensions of the prints compared with their negatives. The total linear changes in a print, measured in the direction of the principal and horizon lines, may readily be found by comparing the distances between the "teeth" (metal plates permanently marking the principal and horizon lines in the image plane of the camera) on the negative with those included between their contact prints on the positive.

With reference to Fig. 52, Plate XXVIII, we have:

ab = original length of horizon (or principal) line between the teeth of the camera or between their imprints on the negative;
$a'b'$ = the corresponding length measured on the positive;
$CO=f$ = constant focal length of the camera or negative.

The focal length $c'O$ of the contracted (or expanded) positive may be found graphically by drawing the triangle abO, placing the line $a'b'$ (measured on the positive) parallel with ab and moving it (maintaining its direction parallel to ab) towards (or from) O until a' falls upon aO and b' upon bO.

$c'O$ will be the focal length to be applied when considering the horizontal angles deduced from the positive. Had ab been measured in the direction of the principal line, $c'O$ would be the focal length for the positive to be considered when deducing vertical angles from the point. The focal lengths $c'O$ should be

ascertained for every print that is to be used in the iconometric map construction.

The topographic map proper is constructed iconometrically from the negatives and positives in a manner very similar to that described under Col. Laussedat's method.

Referring to Fig. 53, Plate XXIX, we have:

I and II = negatives of plates exposed at stations I and II respectively. I shows the image of a signal at station II, and negative II shows the image of a signal at station I;

$I\ II$ = base line measured between the two camera stations I and II.

Both negatives show the image t of the same tower T.

2. Orientation of the Picture Traces on the Plotting-sheet.

After the base line $I\ II$, Fig. 53, Plate XXIX, has been plotted in reduced scale we describe circles about I and II with the radius equal to the constant focal length of the negatives,

$$cO = f,$$

and produce the line $I\ II$ beyond both station points, make

$$I\ II_0 = O\ II_0 \text{ (Plate I)}$$

and

$$II\ I_0 = O\ \ I_0 \text{ (Plate II)},$$

describe arcs from II_0 as center with $II_0c = x^{\mathrm{I}}_{\mathrm{II}}$ (Plate I) and from I_0 as center with $I_0c = x^{\mathrm{II}}_{\mathrm{I}}$ (Plate II) as radius.

cII_0 will be the trace of picture I and cI_0 will be the picture trace of II oriented at station II with reference to the base line $I\ II$ (Plate XXX).

Fig. 54, Plate XXX, illustrates a more simplified way of orienting the picture traces.

After the base line $I\ II$ has been plotted the horizontal angles α^{I} and α^{II} (azimuthal deflections of the optical axis from the

base line $I\ II$ for the negatives I and II) are plotted at I and II with reference to their positions in regard to the principal planes at the stations I and II as shown in the negatives I and II (whether the station's image falls to the right or to the left of the principal line).

The constant focal length $=f$ of the negatives is laid off on the principal line $=c'O$ for negative I and $=c''O$ for negative II. The images of the stations are projected upon the horizon lines, S_{II} upon $H_I H_I$ (Plate I) and S_I upon $H_{II}H_{II}$ (Plate II), when

$c'OS_{II}=\alpha'$ = horizontal angle included between the principal plane and base line $I\ II$, and
$c''OS_I=\alpha''$ = corresponding horizontal angle for station II.

These angles, α' and α'', are transferred from the negatives I and II to their corresponding ends of the base line $I\ II$, as indicated in Fig. 54, Plate XXX. Now lay off the focal length f from the base stations I and II upon the sides of the angles α' and $\alpha''=Ic'$ and $=IIc''$ respectively, and erect perpendiculars $H'H'$ and $H''H''$ to Ic' and IIc' in c' and c'' respectively. They will represent the traces in horizontal plan of the vertical picture planes I and II in correct position and orientation with reference to the base line $I\ II$. The remaining two sets of five plates each of the panoramas at the stations I and II are easily oriented and plotted; the next plate in order at station II, for instance, would have the principal ray (optical axis) in the direction $(\alpha''+60°)$, the third $(\alpha''+120°)$, etc., Fig. 55, Plate XXXI. Every plotted camera station will be surrounded by a regular hexagon the sides of which represent the picture traces of the six negatives forming the panorama set for the station.

3. Locating Points, Identified on Several Photographs, on the Plotting-sheet.

The horizontal locations of all points identified on two or more plates are plotted by locating the intersections T of the lines of horizontal directions It', $II\,t''$, $III\,t'''\ldots$, Fig. 54,

Plate XXX, in the same manner as has been described for Col. Laussedat's method.

4. The Iconometric Determination of Elevations of Pictured Terrene Points.

The elevations of points iconometrically plotted are found in the same way as described for Col. Laussedat's method. If the scale of the map is $\frac{1}{M}$ we will have, Fig. 54, Plate XXX, the elevation of station I above $II = H = I(S_{\text{I}})$.

$$I(S_{\text{I}}) = M \cdot y_s \frac{I\,II}{S_{\text{I}}\,II}.$$

The values of $y_s = S_{\text{I}}(S_{\text{I}})$, $I\,II$ and $S_{\text{I}}\,II = l''$ are found by direct measurement with a small ivory beveled scale divided into 0.5 mm., of which 0.1 mm. may well be estimated after some little practice.

C. Capt. E. Deville's Method (Canadian Method).

This so-called Canadian method has been in use under the auspices of the Canadian Department of the Interior since 1888. Capt. Deville, Surveyor-General of Dominion Lands, has given a detailed account of his methods in "Photographic Surveying," published at the Government Printing Bureau in Ottawa in 1895, and the following paragraphs have been largely taken from Deville's book.

1. General Remarks on the Field-work.

The area to be surveyed is covered with a triangulation net, preferably before the phototopographic work is begun, and a secondary or tertiary triangulation, if needed, is carried along with the phototopographic work to locate the camera stations, in both the horizontal and vertical sense, with reference to the primary triangulation stations already established.

The surveyor makes a plot of the entire triangulation covering his territory in the field, and he locates on the same all the stations that he may occupy to enable him to recognize the weak points in his scheme and to plan his operations with a thorough understanding and to secure a good assurance of success. The instrumental work in the field is done merely to locate the camera stations and certain reference points (used for the subsequent orientation of the picture traces), all topographic details being deduced from the pictures.

The camera stations are located either by angles taken from the station to surrounding triangulation points (resecting, three-point problem), or by angles observed from the latter to the camera station (intersecting, concluding), or by both methods combined.

The strength or value of the work depends very much upon a judicious selection of the points that are to be used as camera stations, in order to bring the enitre terrene under proper control and to be enabled to construct the map by the method of intersections of lines of direction. Other methods for plotting topographic features and details being employed only when the method of intersections fails on account of insufficiency of data to give the requisite number of horizontal directions (the camera stations not being well situated) for a good location of points by intersections.

Each camera station should be marked with a signal before leaving it, not be shown on the pictures, but to be observed upon with the transit or altazimuth from the triangulation stations, in order to locate the position of the camera station upon the plotting-sheet.

Frequently it will be of advantage to set the camera up eccentrically over a triangulation station, in order to include certain parts of the landscape in the views. The position of the eccentric camera station with reference to the triangulation point can readily be ascertained (by azimuth and distance) and should always be recorded.

Complete panorama sets are not taken at every station; it is preferred, rather, to increase the number of stations, often occupying a special station to obtain a single view only, if by doing so better intersections for the location on the plan of some special feature may be obtained.

Multiplicity of stations demands but a small increase in labor, either in the field in the extra observations of horizontal directions for their location or for plotting them in the office, and enough stations should always be occupied to give a full control of the relief of the area to be surveyed.

A certain section of the terrene may be so located that it will be a difficult matter to select more than one station, whence it may be seen. In such a case the method of "vertical intersections" may often become useful; two or more views of such area may be taken from stations at different *elevations:* the greater the difference in altitude between such stations the longer will the base line be, and the better will be the intersections which locate the features in question (if the latter are not too distant).

As enough plates should be exposed to completely cover the ground, the camera stations will have to be distributed in such a way that all valleys, sinks, and depressions that may be represented in the scale of the map are well controlled (i.e., are seen from different camera stations). It is evident, therefore, that the number of stations to be occupied for the topographic development of a certain area will depend upon the character of the terrene and upon the scale of the chart.

Two or three well-defined points ("reference points") in each panorama section (covered by one plate) are observed with the transit or altazimuth, noting the vertical and horizontal angles upon the outline sketch that is made for every exposed plate.

These sketches serve far better to identify points with certainty than a mere designation (by name or symbol) or description of the points observed upon. The general triangulation notes are kept in the usual manner.

Vertical angles are observed to check the position of the horizon line on every photograph and to correct errors due to small changes in the level adjustments of the camera that may arise during the transportation of the instruments over a rough trail.

The horizontal angles are needed, both for the location of the camera stations and for the orientation of the pictures (picture traces) on the plotting-sheet for the subsequent map construction.

2. General Remarks on the Iconometric Plotting of the Survey.

The field notes of the phototopographic surveys made in the Northwest Territory of the Dominion of Canada by the Topographical Surveys Branch of the Department of the Interior—under Capt. E. Deville, Surveyor-General of Dominion Lands—are plotted on the scale of 1:20000, but the maps are published on the 1:40000 scale with equidistant contours of 100 feet.

The phototopographic reconnaissance in southeast Alaska executed by Dominion Land Surveyors—under W. F. King, Alaskan Boundary Commissioner to Her Majesty—was plotted on the scale of 1:80000, with a contour interval of 250 feet, and it was published on the 1:160000 scale.

After the triangulation has been computed and the points have been plotted, and after the computed elevations have all been affixed to the marked points on the plotting-sheet, the triangle sides of the secondary triangulation scheme executed during the phototopographic survey are computed, the corrections to the horizontal angles, indicated by the closing errors, having been applied. The latitudes and departures from every secondary point to the nearest primary station are then computed and the secondary stations are plotted by their latitudes and departures (unless the primary sides are too long).

All camera stations not already included in the secondary triangulation scheme are now plotted with reference to the triangulation points, using either a table of chords or a station-

pointer (vernier protractor). If many points had been observed upon from the camera station, the horizontal angles are preferably laid off on a piece of tracing cloth or paper and this improvised multiarm protractor is used, like a station-pointer, to locate the plotted position of the camera station.

The surveyor should endeavor to obtain at least one direction from a triangulation station to every camera station; the plotting will then be less troublesome and far more accurate. Photographs should not be used for plotting the positions of camera stations; enough angles should always be observed in the field to locate (trigonometrically) every occupied station in the manner just indicated.

From the original negatives copies are made, enlarged to $9\frac{1}{2}$ by 13 inches, on heavy bromide paper (more recently so-called "Platino Bromide" paper has been used by Capt. Deville). The enlargement adopted in Canada for these bromide prints is about 2.1 times, which ratio was selected to utilize the full width of the paper found in market. These enlargements, being extensively used in the map construction, should be made with great care to reduce distortion to a minimum.

After the prints have been developed (with iron oxalate), well washed in acidulated water and fixed, they are again thoroughly washed and dried in a flat position, under special precautionary measures to control the contraction or expansion, in such a way that the final size of the dry-prints have uniform dimensions. Slight distortions that would arise from a play of the negative carrier in the enlarging camera or from the bromide paper not lying perfectly flat on the surface of the copying-screen are best reduced by using a copying-lens of long focus.

Before using the prints for the map construction any distortion due to the enlarging process should be ascertained, which is best done in the following manner:

Fig. 56, Plate XXXI.—Join the middle notches H and H', P and P', and with a set-square test these two lines for perpendicularity. Take with a pair of dividers the distance of the

two notches A and B, which should be one half of the enlarged focal length and equal to the distance between the two notches C and D. Apply one of the points of the dividers in P and the other should come in E and F. Transfer the point to P' and check $P'G$ and $P'J$. If the print stands all these tests, it may be used iconometrically; if it does not, it is returned to the photographer with the request for a better one.

3. Orienting the Picture Traces on the Working-plan.

Every photograph contains at least one, generally several, of the triangulation points plotted on the working-sheet and the traces of the picture and principal planes are oriented and plotted on the plan as follows:

The distance or principal line PS, Fig. 57, Plate XXXI, is made equal to the focal length and the pictured point α of the reference point A is projected upon the principal line $(=a')$ and upon the horizon line $(=a)$.

If S_1, Fig. 57, Plate XXXI, is the plotted position of the camera station on the plan, and if S_1A_1 represents the horizontal direction to A from the station S, make S_1a_1 equal to Sa (taken from the photograph on the "photograph-board") and from a_1 as center, with $\alpha a' = Pa$ as radius, describe an arc to which S_1p is drawn tangent. S_1p will be the trace of the principal plane (or the distance line) and the perpendicular to S_1p through $a_1 = pa_1$ will be the picture trace. Instead of making this construction on the "photograph-board" (which will be described under section *i*) it may be made on the plan.

On S_1A_1 take S_1B, Fig. 58, Plate XXXI, equal to the focal length, erect BC perpendicular to S_1A_1 and make it equal to the abscissa $(=\alpha a'$, Fig. 57) of the reference point. Join S_1C and take S_1p equal to the focal length; at p erect a perpendicular to S_1C and it will be the trace of the picture plane, S_1C being the trace of the principal plane.

Another simple method for orienting the picture trace of a photograph having the image of a reference point C is as follows

(Fig. 59, Plate XXXII): Take a triangle of hard rubber or wood and mark off along one side the focal distance *SP*, Fig. 57, Plate XXXI, equal to *ab*, Fig. 59, Plate XXXII, from the right-angle corner *a*. Carefully notch the triangle side at *b* so that the center of a fine needle marking the plotted station point will fit into the notch. From the photograph take the abscissa ($a'\alpha = +a$, Fig. 57, Plate XXXI) of the pictured reference point (α) between the points of a pair of dividers, move the triangle about the needle, marking the plotted station *b* with the left hand until *ac*, Fig. 59, Plate XXXI, is equal to the distance $a'\alpha$ (abscissa of reference point), held between the points of the dividers. The triangle is securely held in this position and lines are drawn along the triangle sides *ab* and *ac*. Produce *ac* beyond *a* and check the distance *ac* again to be equal to $a'\alpha$. The line *bc* represents the horizontal direction from the plotted station *b* to the plotted reference point *C* (its image on the negative, Fig. 57, Plate XXXI, was α) and we will now have:

ba = trace of the principal plane;

ac = trace of the picture plane;

a = projection of the principal point on the plotting-sheet.

The trace of the principal plane = *ab* is preferably marked by a short line only, bearing an arrow pointing toward the plotted station whence the picture was taken, and the principal point *a* is marked to correspond with the designation of the print, and it may be remarked here that as few constructive lines as possible are drawn on the working-sheet to avoid confusion and mistakes (see photograph-board, section 10, page 148).

4. The Identification of Pictured Points in Photographs Representing Identical Points of the Terrene.

The survey being plotted, analogous to a plane-table survey, mainly by intersections of horizontal lines of direction, points controlling the same area must be identified on pictures taken from different stations. When selecting such points on a photograph, preference should be given to such that best define the

surface or terrene like characteristic points of mountain ridges, peaks, saddles, points at the changes of slope, bends in streams, etc., each point being marked by a dot in red ink on the photograph and affixing a number or symbol to it. It will now be necessary to identify as many of these points as possible on other photographs covering the same area, marking these also by dots and giving identical points the same designation, by number or by symbol in red ink, as on the first photograph.

The identification of geodetic points on several pictures offers no serious difficulty, and with some practice as many points as may be needed for a full development of the terrene, even under different illumination of the pictured areas, may be picked out with rapidity and precision. In case of doubt, beginners may resort to Prof. Hauck's method, which has already been mentioned several times in the preceding pages.

5. Application of Prof. Hauck's Method for the Identification of Terrene Points Pictured on Several Photographs.

The two photographs, picturing the same areas as seen from different stations or points of view, are pinned side by side on a drawing-board. The images of the camera stations whence the pictures were obtained are kernel points; if they fall outside of the limits of the pictures their projections on the picture traces may be determined from the plotting-sheet or working-plan. The parallels to the principal lines, on which the scales are to be placed, are drawn as explained in Chapter IV, paragraph VII, section 2, and the scales are fixed in position.

A fine needle is inserted into the drawing-board through each of the kernel points and the loop at one end of a fine silk thread is dropped over the needle, the other end of the thread being fastened to a small weight by means of a slender rubber band (see Fig. 60, Plate XXXII).

A well-defined point is now identified on the two photographs sufficiently far from the kernel points, and one thread is moved (by taking the small weight in one hand) to pass

through the point identified on the photograph; the weight is deposited on the drawing-board, holding the thread in this position under slight tension of the rubber band *b*.

The same operation is repeated with the other thread and the other photograph, when the two threads should intersect the scales at the same division mark; if they do not, one of the scales is to be moved until identical division marks are bisected by the two threads. The identification of other geodetic points pictured on both photographs may now be proceeded with:

Having selected a characteristic geodetic point on one of the photographs, the corresponding thread and weight are moved until the thread bisects that point. Noting the point of intersection on the scale by the thread in this position, the other thread is now moved to bisect the corresponding graduation mark on the second scale. The second thread will then also bisect the corresponding image of the same geodetic point on the second picture.

6. Plotting Pictured Terrene Points as the Intersections of Lines of Horizontal Directions. Iconometric Plotting of Terrene Points in General ("Horizontal Intersections").

After enough pictures have been selected to develop a certain area, and the identification and marking of the images of corresponding geodetic points have been completed, projections of all these points on the horizon lines of the pictures are marked and transferred to the straight edge of a strip of paper, including in this transfer the marking on the strip's edge of the principal point of every photograph.

The strips are given the same designation as the pictures to which they belong (by number or symbol) and they are then placed upon their picture traces on the plotting-sheet in such a manner that the principal points of picture trace and paper strip coincide. They are secured in this position on the working-sheet by means of small weights or fine thumb-tacks.

To plot the horizontal projection of a geodetic point, shown and marked on two photographs and marked on the correspond-

ing paper strips, two fine needles are inserted into the plotted stations *I* and *II*, Fig. 60, Plate XXXII, of the two photographs. A fine silk thread is attached to each needle. The other end of the thread is connected with a small weight *W* by means of a fine rubber band *b*.

The thread looped over station needle *I* is now moved over the paper strip (indicating the picture trace on the plan) until it bisects the projection a' of the geodetic point's image. The weight is now placed upon the paper, holding the thread under slight tension of the rubber band in this position.

The second thread, connected with the needle in station *II*, is placed over the horizontal projection a'' of the image of the same point *A*. The point of intersection *A* of the two threads will be the desired position on the plan of the point *A*.

After this position of *A* upon the plotting-sheet has been checked by means of another photograph taken from a third station *III*, and containing the image a''' of the point *A*, its plotted position is marked by a dot in red ink and its designation, corresponding with that given on the prints, is also affixed in red ink. A sufficient number of points having been plotted in this manner, and all having been supplied with the same letters or numerals (in red ink) that had been given their images on the photographs, their elevations are determined and also affixed to the points in red ink. Frequently the designation of the point by letter or numeral is added in pencil on the working-sheet, to be erased after the elevation of the point has been affixed to it in red ink.

In case the strips of paper on the picture traces should overlap, as shown in Fig. 61, Plate XXXII, the part *CD* of the picture trace *PQ* is marked off on the strip *MN* lying under it, the band of paper *PQ* is then placed in proper position and the marks on its edge are transferred to the line *CD*. The strip *PQ* is now placed under *MN*, the marks on the latter, along *CD*, serving the same purpose as those of *PQ*.

When a station, *A*, Fig. 62, Plate XXXII, falls so close to

the edge of the working-sheet that the trace QR of the picture plane falls outside of the limits of the plan, then the trace AC of the principal plane may be produced to B, AB being equal to AC=focal length of the picture, and MN, drawn perpendicular to BC or parallel to QR, will occupy with reference to QR the same position as the focal plane of the camera does to the image plane of the perspective.

The direction of a point of the photograph projected in Q on the picture trace is found by joining NA and producing to the opposite side of A.

As already mentioned, the intersection of two lines of direction, establishing the plotted position of a geodetic point, pictured on two photographs, should be checked either by a third line or otherwise, before the position of such point should be accepted on the plan as correct.

Such intersections may, for instance, be checked by determining the elevation of the point from both photographs. Unless the point has been correctly plotted, these two heights will not agree. This check, however, does not guard against slight errors in position.

A check may also be obtained by drawing a line, on which the point may be situated (for instance, the shore line of a river or lake), with a perspectograph or perspectometer; still, the best check will always be afforded by a third intersecting line of direction obtained from a third photograph.

7. Iconometric Plotting of Pictured Terrene Points by So-called "Vertical Intersections."

We have seen how the base line between two stations is projected into horizontal plan when using the method of intersections of horizontal lines of direction, hitherto considered, but when two camera stations are occupied at different elevations, and not far apart horizontally, to locate geodetic points by intersections of lines of direction, the so-called "method of vertical intersections" may be employed with advantage.

With this method the base line—its horizontal projection being either too short or more frequently falling into the same direction with the distant points to be located by the intersections of lines of direction—is projected upon a vertical plane.

The greater the difference in elevation between the two stations the greater will the length of this vertically projected base line be and the more accurate will be the iconometric location of the points by lines of direction.

We have, with reference to Fig. 63, Plate XXXIII, two camera stations A and B, two photographs A_N and B_N obtained from them and containing the image d_A and d_B of the identical geodetic point D. It is assumed that the horizon plane through the lower station B be the ground or plotting plane, and that the principal plane of the photograph A_N be the vertical plane of projection which is revolved about its trace into the horizon plane of B.

a = horizontal projection of station A;
aB = horizontal projection of the base line AB;
$H_{AB}H'_{AB}$ = picture trace of photograph A_N in horizon plane of B (plotting-plane);
$H_B H_B'$ = picture trace of photograph B_N in horizon plane of B;
$aP_A' = BP_B'$ = constant focal length of the negatives A_N and B_N;
aP_A' = trace of principal plane passing through aP_A' in horizon plane of B.

To plot the position d' of a point D (pictured in A_N as d_A and in B_N as d_B) in the plotting-plane the rays Ad_A and Bd_B are projected upon the vertical plane (revolved about aP_A' into the ground plane), when (d_1) will represent their point of intersection d projected into that same vertical plane (revolved about aP_A' into the plotting-plane).

The ray $Ad_A = AD$ intersects or penetrates the picture plane A_N at a distance $= d_A d'_{AB}$ vertically above the ground plane (above the picture trace or ground line $H_{AB}H'_{AB}$ of picture A_N).

This ordinate is laid off upon $P_A'H_{AB}=P_A'(d_A)$, when d_A will be the projection on the vertical plane of pictured point d_A.

The vertical through a projected upon the vertical plane is represented as $a(A)$, and if we make

$a(A)=P_AP'_{AB}$ (picture A_N)
=difference in elevation between the two stations B and A,

(A) will be the upper camera station A projected into the vertical plane, and the line $(A)(d_A)$ will be the projection of the ray Ad_A, or AD, upon the vertical plane (revolved about aP_A' into the plotting-plane).

The ray $Bd_B=BD$ intersects the second picture plane B_N in d_B. If we draw through d_B (projection of d_B on ground line H_BH_B') a perpendicular to $aP_A'=d_B'd_{1B}$, d_{1B} will be the projection in the vertical plane of the horizontal projection in the picture trace of the pictured point d_B. Producing $d_B'd_{1B}$ beyond d_{1B} and making $d_{1B}(d_B)=d_Bd_B'$ (measured on the negative B_N) will locate at (d_B) the projection of the pictured point d_B upon the vertical plane.

The perpendicular to aP_A' through B locates the projection into the vertical plane$=b_1$ of the plotted station B, hence the line $b_1(d_B)$ will be the projection into the vertical plane of the ray $Bd_B=BD$.

The intersection (d_1) of $b_1(d_B)$ with $A(d_A)$ locates the projection into vertical plane of the point d, and the horizontal projection of the point D (plotted on the ground plan) will be on the line $(d_1)d'$, which is the vertical through d (perpendicular to aP_A' in our case) passing through (d_1) and produced beyond d_1', and either horizontal line of direction ad_A' or Bd_B, produced to intersect this perpendicular $(d_1)d_1'$, will locate the position d' (of the point D) on the plotting-sheet with reference to the plotted stations A (or a) and B.

(The location of d' as the intersection of the horizontal directions ad_A' and Bd_B' would not be very accurate in our case, and far less so for points pictured on the other side of the prin-

cipal point P_B, the angle of intersection of their horizontal directions being even smaller than at d'.)

The point d_1' being the projection into the vertical plane of the point d' (the horizontal projection into the ground plane of the point d), the length $(d_1)d_1'$ (measured on the plotting-scale) will represent the elevation of the point D above station B (or above the ground plane).

8. Iconometric Determination of the Elevations of Pictured Terrene Points.

Generally speaking, one perspective is insufficient to determine the elevation of a point, although there are exceptions, like the points on the horizon line of a photograph which have the same elevation as the camera station. A single photograph would also suffice if the distance from the camera station to the point to be determined vertically be known; for instance, Fig. 64, Plate XXXIV, the horizontal projection d of the point D being known, its height H above the ground plane will be the fourth proportional to the three known lines Bd_1, Bd_{1B} and $d_{1B}(d_B)$:

Bd_1 = horizontal distance between the plotted station B and the plotted point, measured in the plotting-scale of the working-sheet;

Bd_{1B} = horizontal distance between station B and projection of pictured point d_B in the ground line H_BH_B', measured on the plan;

$d_{1B}\,(d_B) = h$ = ordinate of pictured point d_B, measured on the picture plane ($=d_B'd_B$, Fig. 63, Plate XXXIII, picture B_N),

and the value for H may be computed from the equation

$$H = h\frac{Bd_1}{Bd_{1B}}.$$

If we now project the plotted point d_1 and the pictured point d_B into the principal plane and revolve the latter about the prin-

cipal line BP into the plotting-plane, we will have with reference to Fig. 64, Plate XXXIV,

$P(d_B') =$ height of pictured point d_B above the horizon plane $= h$;
$(d_B') =$ pictured point d_B, projected into the principal plane and revolved with the latter into the horizon or plotting plane;
$(d')d_1' =$ vertical distance of the point d above the horizon plane $= H$.

This height, H, is the fourth proportional to the three known lengths Bd_1, Bd_{1B} and h;

$BP =$ focal length of the print $= f$;
$P(d_B') =$ ordinate of the pictured point above the horizon line (to be measured on the photograph), and
$Bd_1' = f + Pd_1'$, where $Pd_1' =$ vertical distance between the plotted point d_1 and the picture trace $H_BH_B' = d_1\delta$ (to be measured on the plotting-sheet),

its value may be found with the aid of an ordinary sector, Fig. 65, Plate XXXIV, in the following manner:

Take with a pair of dividers the (ordinate) distance from the pictured point d_B to the horizon line (on the photograph) place one point of the dividers on the division c of the sector, when $CO =$ focal length of the photograph, and open the arms of the sector until the second point of the dividers coincides with the corresponding division D of the other sector arm (OD being equal to $OC =$ focal length). Now take with the dividers the horizontal distance ($d_1'P = d_1\delta$, Fig. 64, Plate XXXIV) of the plotted point d_1 from the picture trace H_BH_B', place one of the points in C and note where the second point of the dividers intercepts the scale OC, say at A. Turn the dividers about this point A (maintaining the opening of the sector unchanged) and place the second point of the dividers upon B on the scale OD—B corresponding to A, or $OB = OA$—when AB, measured on the plotting-scale, will represent the height, H, of the point d above the horizon plane of the station B.

9. Iconometric Determination of the Elevations of Pictured Terrene Points by Means of the So-called "Scale of Heights."

Another method for determining the elevations of plotted points iconometrically consists in the use of the so-called "scale of heights," Fig. 66, Plate XXXV.

Make SP equal to the focal length of the photographic perspective, erect PA perpendicular to SP in P, and divide both lines into equal parts. Join the points of division on PA to S and through those of SP draw lines parallel to PA.

To use this scale of heights with a pair of dividers, take from the photographic perspective the (ordinate) distance from the pictured point to the horizon line and transfer it to the line $PA = P\mu$. The point μ may be found to correspond to the line $S\mu$, passing through the division mark 9 of the graduation on PA. With a pair of dividers take the vertical distance from the horizontal projection of the point to the plotted-picture trace (measured on the working-sheet) and transfer it to SP to the right or to the left of P according to the position of the plotted point with reference to the picture trace, whether beyond the picture trace or between the same and the plotted station.

In Fig. 66, Plate XXXV, it is shown as falling between the station and the picture trace into m. The line mB, parallel with PA, is intersected by $S\mu$ in M, and the distance mM, measured on the plotting-scale, will be the height of the point M above (or below) the station horizon.

A scale, Fig. 67, Plate XXXV, is conveniently pinned, somewhere on the plotting-board, perpendicularly to a line AB; the division C of this scale, bisected by the line AB, corresponds to the height of the camera horizon. Placing one of the legs of the dividers with which the length AB was taken off the "sector," Fig. 65, Plate XXXIV, or with which the length mM was taken off the "scale of heights," Fig. 66, Plate XXXV, in C, Fig. 67, Plate XXXV, the division D of the scale, coinciding with the other point of the dividers, will indicate the height

of the point above the plane of reference or datum plane This height is entered in pencil on the plan, inclosed in a small circle to distinguish it from the number of the point. It is checked by means of a second photograph, and when the discrepancy between several values for the elevation of the point falls within the limits of permissible error, their mean is entered in red ink on the plan and all pencil figures are erased.

Any marked difference in the values for the height obtained from two photographs would indicate that the two points of which the elevations were determined are not identical points or that an error had been made in plotting the same or in determining its height.

A third intersection would dispose of the first two alternatives and a new measurement of the height will show whether an error has been made, or whether the discrepancy is due to unavoidable errors.

10. The Use of the So-called "Photograph-board."

The various constructions described in the preceding pages if made directly on the photographs would obscure many details and produce confusion through the intricacy of the auxiliary lines. Capt. Deville, therefore, had a special drawing-board prepared on which as many of the construction lines are drawn, once for all, as would have to be repeated for the different prints of uniform size (which were, of course, obtained with the same camera).

This so-called "photograph-board" is an ordinary drawing-board covered with tough drawing-paper the surface of which is to represent both the picture plane and the principal plane (both planes revolved into the horizon plane), and it is used in conjunction with the photographic perspectives, using the negatives when great accuracy is required, or using solar prints for general plotting.

Two lines *DD* and *SS′*, Fig. 68, Plate XXXV, are drawn at right angles to each other; they represent the horizon and

principal lines, while $PD = PD' = PS = PS'$ are equal to the focal length, so that D, D', S, and S' represent the left, the right, the lower, and the upper distance points respectively.

The photographic perspective is placed in the center of the board, within the rectangle $TYOZ$, the principal line coinciding with SS' and the horizon line with DD', and it is secured in this position by means of small thumb-tacks, pins, etc. The four scales forming the sides of the rectangle $OTYZ$ serve to locate lines parallel with either SS' or DD' on the perspective (without actually drawing those lines).

At a suitable distance from D' a line QR is drawn perpendicular to DD', and on it are laid off, by means of a table of tangents, the angles formed with DQ by a series of lines drawn from D as a center. This scale, QR, is employed when measuring the altitudes or the azimuthal angles of points pictured on the perspective, as will be explained in a following paragraph.

From S as a center with SP as radius an arc of a circle PL is described and the latter is divided into equal parts. Through the points of division of PL lines converging to S are drawn between PL and PD'. The lines MN are drawn parallel to the principal line, as shown in Fig. 68, Plate XXXV, and these lines are all used in connection with the scale of degrees and minutes QR.

The studs of the centro-lineads are fixed in A, B, C, and E, the lines AB and CE joining their centers, and those needed for adjusting the centro-lineads are drawn and used in the manner to be explained in Chapter X.

A square, $FGKH$, is constructed on the four distance points, Fig. 68, Plate XXXV.

11. Iconometric Plotting of the Trace of a Figure's Plane.

If one wishes to use a perspective instrument for converting a figure—situated in an inclined plane of which the perspective photograph) is given—into the projection of the figure into

horizontal plan it will be necessary to locate the traces of the figure's plane in both the principal and picture planes.

We may distinguish between two cases frequently met with in practical work:

(1) The inclined plane containing the figure may be given by its line of greatest slope.

(2) The inclined plane containing the figure may be given by three points.

First Case.—The inclined plane of the figure may be given by the line of greatest slope, which may be an inclined road-bed, the drainage line of a straight valley (thalweg), the surface of a glacier, etc.

This line of greatest slope may be represented on the plan by a line ab, Fig. 69, Plate XXXVI, the altitude of a being known.

The photographic perspective is pinned to the photograph-board, and the ground line XY is drawn, taking the horizontal plane through a as ground plane.

On the plotting-board aO is drawn through a perpendicular to the horizontal projection ab of the line of greatest slope AB, and it is produced to its intersections L and O with the principal line S_1p_1 and with the picture trace X_1Y_1.

On the photograph pE is made equal to p_1b, at E a perpendicular to XY is erected and produced to the intersection β with the pictured line $\alpha\beta$, representing the line of greatest slope AB. If we make pN, on the photograph-board, equal to p_1O of the plan and join N with β on the picture, this line $N\beta$ will represent the trace of the required plane on the picture plane. If pQ is made equal to p_1L and Q is joined with M, MQ will represent the trace of the required plane, revolved about SS', on the photograph-board, into the picture plane, the station S falling in D.

Producing MQ to R, DR will represent the vertical distance of the station S above the plane $RM\beta$.

Second Case.—The inclined plane containing the figure is given by three points.

Take for ground plane the horizontal plane containing one of the points, a, Fig. 70, Plate XXXVII, and draw the ground line XY on the photograph. Join a on the plotting-sheet to the two remaining points and produce these lines to their intersections E and F with the picture trace. On the photograph make p_1K equal to pE and draw KL perpendicular to XY; join the perspectives α and β of the points shown as a and b on the plan and produce to the intersection with KL. Take p_1T equal to pF, draw TN perpendicular to XY and produce to the intersection N with the line joining the perspectives α and γ. Join N and L, when NL will represent the trace of the required plane on the picture plane.

Produce LN to O and take pG equal to p_1O; join a and G and make p_1Q equal to pH. The line MQ will represent the trace of the required plane on the principal plane revolved about SS' into the picture plane, the station being in D. Here also DR is the vertical height of the station above the plane containing the three given points.

12. Iconometric Contouring.

After the heights of a sufficient number of points have been determined to give a good development of the terrene that is to be mapped, the contour lines are drawn in by interpolation between the points of which the heights had been established.

In a moderately rolling country a limited number of points of known elevations will suffice to draw the contour lines with precision, but in a rocky region, where abrupt changes and irregular forms predominate, it is almost impossible to plot enough control points to enable the iconometric draughtsman to render a faithful representation of the relief of the broken terrene, and it is here that a close and minute study of the photographs becomes indispensable to modify the courses of the contours to represent the characteristic features of the terrene.

The value of photographic views for the cartographic delinea-

tion of the topography of a mountainous area is generally acknowledged by experienced topographers, even when using instrumental methods exclusively for all the control work. A minute study of the pictured terrene will always be of great aid to the draughtsman (when inking the topographic sheet), to draw the contours of which the main deflections had been located instrumentally, with a more natural and artistic reproduction of nature's forms, than could be attained by mechanically inking the pencilled lines as obtained by instrumental measurements and free-hand sketching alone.

Instead of drawing the contour lines at once upon the plan, the draughtsman may begin by sketching them on the photographs first, following the same rules for their location (by interpolation), as if he were drawing them on the plan, for the image of every plotted point is already marked on the photographs and its elevation may readily be taken from the working-plan. By adopting this plan he will be enabled to follow the inequalities of the surface very closely and the perspectives of the contours thus drawn on the pictures will greatly facilitate the drawing on the plan of their horizontal projections. They may also be transferred to the plan by means of the perspectograph or perspectometer if accuracy is to give place to rapidity in the map production.

A sufficient number of tertiary points having been plotted by the method of intersections, there will be little difficulty in drawing the contour lines by interpolation between such points. It may happen, however, that the control points are too few in number and too far apart to give a good definition of the terrene (in a topographic reconnaissance), and then it will become necessary to resort to less accurate methods for locating the contours on the plan. For example, the ridge *abcd* of a mountain range, pictured on a photograph as $\alpha\beta\gamma\delta$, Fig. 71, Plate XXXVIII, may be divided by the contour planes by assuming it to be contained in a vertical plane.

On the plan we produce the projection *ad* of the ridge to

the intersection F with the picture trace and draw through the station S_1 the line S_1C parallel to ad.

The photograph having been pinned to the photograph-board, take from the principal point on the horizon line PV equal to p_1C and PG equal to p_1F. At G place the scale of equidistances perpendicular to the horizon line HH', the division at G corresponding to the height of the station, and join the marks of the scale (corresponding to the elevations of the contour planes) to the vanishing point V.

Having thus located the points of intersection of the ridge by the contour planes, their distances (abscissæ) from the principal line are now marked upon the edge of a strip of paper and their directions plotted in the usual way. The intersections of the radials (drawn from S_1 to the points marked on the paper strip) with ad will give the intersections of the contour lines with the ridge ad.

When the mountains have rounded forms showing no well-defined ridges, the visible outline, silhouetted on the photograph, may be assumed to be contained in a vertical plane perpendicular to the line of direction drawn to the middle of the ridge outline, or silhouette.

The construction may be made by drawing, on the photograph-board, SV perpendicular to the direction SM of the middle of the outline, Fig. 72, Plate XXXIX; p_1M_1 on the plan is made equal to PM, and from the projection a of the summit of the mountain a perpendicular ac is let fall on S_1M_1, which represents the projection of the visible outline. It is produced to the intersection N with the picture trace. PQ is taken equal to p_1N and the scale of equidistances is placed at Q, perpendicular to the horizon line. The points of division are joined to V, these radials are produced to intersect $\alpha\gamma$, and the plotting of the contour points along $\alpha\gamma$ is done in the same way as described in the preceding case, or the directions of the intersections of $\alpha\gamma$ by the contour planes may simply be plotted and the contour lines drawn tangent to these directions.

The horizon line, containing the perspectives of all points of the same elevation as the camera station, represents the perspective of a contour line when the horizon plane coincides with a contour plane.

The topographic draughtsman should pay particular attention to geologic forms and to the originating causes of the topographic features, as without such knowledge the correct interpretation of such forms by means of contours and a faithful cartographic representation of the various terrene forms would require the cartographic location of a vast number of control points.

Although the terrene forms often result from the successive, or from the combined, actions of many agencies, they will yet have similar characteristic shapes when resulting from the same causes, and the cartographic representation of such typical terrene forms (produced by identical agencies) should also show a corresponding characteristic similarity in the contour forms.

13. The Use of the So-called "Photograph-protractor."

The angle included between the line of direction to a point of a photographic perspective and the principal and horizon lines (the altitude and azimuthal angle) is sometimes wanted in arc measure.

The azimuthal angle of the line of direction to a point *A* may be obtained at once on the photograph-board by joining the station *S*, Fig. 73, Plate XL, to the projection *a* of the pictured point on the horizon line.

If required in arc measure, the distance *Pa* is transferred to the principal line $= PG$, *D* is joined to *G* and produced to intersect the scale of degrees and minutes *BC*, where the graduation mark *K* indicates the value of the azimuthal angle in arc measure.

When many such angles are to be measured, the horizontal scales *TY* and *OZ*, Fig. 68, Plate XXXV, may be divided into

degrees and minutes by means of a table of tangents, using the focal length SP as radius.

The altitude is the vertical angle at S, Fig. 73, Plate XL, of the right-angle triangle, having for sides Sa and $a\alpha$. To construct it, take DF equal to Sa, draw FE parallel and equal to $a\alpha$, join D and E and produce DE to the scale (BC) of degrees and minutes.

This construction will be facilitated by the lines previously drawn on the photograph-board. With a pair of dividers take the distance (abscissa) from α to the principal line, carry it from P, Fig. 68, Plate XXXV, in the direction PD', and from the point so obtained take the distance to the arc ML, measuring it in the direction of the radials marked on the board, which will be the distance PF. Then with the dividers carry $a\alpha$ to FE, which is that one of the series MN of parallel lines, Fig. 68, Plate XXXV, which corresponds to the point F. The construction may now be completed in the manner already explained.

A protractor may be constructed to measure these angles directly. It consists of a transparent plate on which lines are drawn parallel to the principal line containing points of the same azimuth and curves containing points of the same altitude.

The azimuthal lines are found by plotting the angles in S and drawing parallels to the principal line SS' through the points of intersection with the horizon line.

If we take the horizon and principal lines as axes of coordinates and denote the altitude of a point pictured as α by h, the equation of the curve of altitude h may be written

$$y^2=(x^2+f^2)\tan^2 h.$$

This also is the equation of a hyperbola of which the principal and horizon lines are the transverse and conjugate axes and of which the principal point is the center.

One of the hyperbola's branches represents the points above the horizon and the other branch those of equal altitude below the horizon.

The asymptotes are lines intersecting each other at the principal point and making angles equal to h with the horizon line. This hyperbola is the intersection by the picture plane of the cone of visual rays forming the angle h with the horizon.

These hyperbolic curves of equal altitude may be obtained by computation, using the preceding formula and substituting different values for h, or they may be obtained graphically by plotting a series of points for each curve, reversing the construction given above for finding the altitude of the pictured point α, Fig. 73, Plate XL. The angular distance between the lines representing points of equal azimuths or those of the same altitude depends on the degree of precision aimed at.

The complete protractor is shown in Fig. 74, Plate XL. It may be made in the same manner as mentioned for the perspectometer by drawing it on paper on a large scale, reducing it by photography, and finally making a transparency by bleaching the negative in bichloride of mercury.

D. Method of V. Legros for Locating the Horizon Line of a Vertically Exposed Plate.

Commandant Legros recommends the use of these hyperbolic curves for the location of the horizon line of a vertically exposed plate.

When the camera with the photographic plate adjusted in vertical plane is rotated horizontally, the plate remaining vertical, any point α, Fig. 74, Plate XL, will describe a hyperbola $\alpha\alpha'$ in the picture plane (on the ground-glass plate). The nearer α approaches the horizon line the smaller the curvature of its hyperbolic trace on the ground-glass plate will become, and that point, α°, which traverses the ground-glass plate in a straight line, HH', will have the same elevation as the second nodal point of the camera-lens—its angle of elevation will be $= +O$, or HH' will be the horizon line of the plate.

To locate the horizon line experimentally in this way the

ground glass is best provided with a series of equidistant horizontal and vertical lines, after the manner of Dr. Le Bon's ground-glass plates.

E. Prof. S. Finsterwalder's Method for the Iconometric Plotting of Horizontal Contours.

Prof. Finsterwalder's method for plotting horizontal contours is well adapted for the development of the terrene forms of a moderately rolling country and it is based upon the following consideration:

The pictured outline of a terrene form may be regarded as the trace of the terrene surface in a plane (picture plane) vertical to the plotting or ground plane.

The camera stations should be specially selected with reference to the use of this method with a view toward obtaining pictures with a sufficient number of such outlines, or silhouettes, of the terrene forms to enable the iconometric draughtsman to give a good definition of the relief of the terrene to be plotted.

These terrene-form silhouettes may be regarded as falling within vertical planes and the rays drawn from the point of view to the pictured points of the silhouette will form a cone, with apex in the second nodal point of the lens (or point of view), its base being formed by the pictured outline (silhouette) of the terrene. A horizontal plane containing a contour A will intersect such a cone of rays in a curve B, the latter touching A in one point.

If we designate by h the difference in elevation between the station (whence the picture was obtained) and the horizontal contour A, by β the vertical angle of each radial or visual ray drawn to each point of the silhouette, then the curve B may be plotted on the working-sheet by laying off, upon a few rays, from the plotted station to points of the pictured outline the corresponding distances

$$h \cot \beta,$$

and the points thus located on the radials drawn from the station point, if connected by a continuous line, will represent the curve *B*, plotted in horizontal plan.

The direction of the silhouetted outline is now plotted on the plan, and where it bisects this curve *B* will be a point of the contour *A*. As we, naturally, would draw not only one curve *B* but a series of them corresponding to several horizontal planes, passing through a series of contours *A* of various elevations, the construction may be simplified, inasmuch as the curves *B*—being the lines of intersection of the same cone of rays with a series of parallel planes containing the horizontal contours—will all be similar in shape, their corresponding points having the same relative positions with reference to the plotted station, and the value $h \cot \beta$ need only be determined for one point of the remaining curves *B* if one curve *B* had been drawn; the others will be parallel to it.

CHAPTER VII.

CAMERA-LENSES.

THE general theory and laws of optics as applied to lenses are the same whether the latter are to be mounted in telescopes or in photographic cameras. The camera may even be regarded as an incomplete telescope, lacking only a suitable eyepiece to convert it into a telescope.

Still, photographic lenses are to fulfill requirements differing widely from those of telescopes, the main difference being in the field commanded by either. As only the central part of a telescopic lens is utilized for observing, comprising a field of but a few degrees, spherical and chromatic aberration do not affect the latter. Phototopographic lenses, however, should command as wide an angle as possible (over 60°) and still produce geometrically true perspectives without distortion, with a sharp definition, a uniformly bright illumination for the entire plane surface of the sensitive plate, and with a great depth of focus.

Rapidity in the action of the camera-lens being desirable, but not of essential importance for surveying purposes, the quality of the lens will in a great measure determine the value of the photogrammeter or photographic surveying camera.

A. The Refractive Index.

With reference to Fig. 75, Plate XLI, we designate by AB the refractive surface, by SI the incident ray, by IP the refracted ray, by CC_1 the perpendicular to the refractive surface in the point where the incident ray SI enters the second medium, by α

the angle included between the perpendicular CC_1 and the incident ray SI, and by β the angle of refraction.

IS being equal to $IP=r$, the ratio of the sines of the angles α and β may be expressed by the ratio of the lines DS and EP, or, in other words,

For all angles α, larger and smaller than the one indicated in Fig. 75, Plate XLI, the ratio between DS and EP will be the same for the same two substances.

This constant ratio is termed the "refractive index" of the two substances that are separated by the refractive surface AB. The incident ray, the refracted ray, and the emergent ray (coming from the same source) are all in one plane.

When speaking of the refractive index of any *one* medium in optics, it is always to be understood that the incident ray has passed through *air* (or space). Thus we have, approximately, if the refractive index for air or space be assumed as unity, the refractive index for

Water, about	1.3
For crown glass, about	1.5
For flint glass	1.6 to 1.9
For diamond, about	2.4, etc.

This means, for instance, that for any angle α (for any incident ray SI) the vertical DS is 1.5 times as long as PE if the ray passes through air and is refracted by crown glass.

B. Refraction of Light-rays.

The preceding consideration enables us to find the means for changing the course of light-rays by refracting them to any amount desirable.

With reference to Fig. 76, Plate XLI, we have AB and A_1B_1 = refracting surfaces of a piece of plate glass.

The incident ray SI arrives at the surface AB under an angle α with the perpendicular IC (perpendicular to AB in I). Glass being denser than air the ray will be refracted toward the per-

pendicular IC, continuing in a straight line IE as long as it passes through this second medium (glass); arriving at E it passes from the denser medium into air and at E it will be refracted away from the perpendicular EC_1 (under an angle α) and continue in the direction EP, parallel to the incident ray SI.

By changing the direction or position of one or of both surfaces of the denser medium (glass) the final direction of EP may be given any course, since the equation

$$\frac{\sin \alpha}{\sin \beta} = n = \text{refractive index}$$

must always be fulfilled.

It becomes plain that the change in the direction of EP from SI will increase directly with the angle included between the two refractive surfaces AB and A_1B_1.

In Fig. 77, Plate XLI, this change in direction is shown for three different glass prisms shaped in such a way that their refractive angles not only decrease from A toward B, but have been given such values that the three rays emanating from a certain luminous point S, after refraction, converge to one point P.

A point P, where several converging rays (originally emanating from a point S in space) intersect one another, is termed an "image point."

C. The Optical Lens.

If the directions not only of three, Fig. 77, Plate XLI, but of an infinite number of light-rays emanating from a luminous point S are to be so changed that all will converge into a point P, we will have to superimpose an infinite number of prisms one upon the other. The heights of these prisms will have to be made infinitesimally small and the refractive angles of two neighboring ones will differ by an infinitesimal small amount.

This means that the broken lines AB and AB_1, Fig. 77,

Plate XLI, will become curves, and a piece of glass with its two faces shaped in such a manner that all light pencils emanating from the same point S will converge to meet in its image point P is termed an optical lens.

Evidently such a lens is a body formed by rotating the figure ABB_1, composed of an infinite number of prism sections, about the line BB_1 as axis. This axis of rotation is termed the optical axis of the lens, and the latter may be considered as composed of concentric zones or rings with spherically shaped outer surfaces. The question now arises what form should be given the figure ABB_1 to obtain a lens that will produce optical images of luminous points.

Opticians can produce in the manufacture of lenses only spherical surfaces with any degree of precision; therefore all optical lenses are inclosed by spherical surfaces. Still, spherical lenses produce well-defined and sharp images of luminous points only within certain limits, limits between which the spherical surface approaches very closely that ideal shape which is best adapted for the purpose in view, but which cannot be manufactured owing to mechanical difficulties encountered in the grinding or cutting process of the lens. In our superficial treatment of the laws of optics—considered inasmuch as they apply to phototopography only—we shall assume that the spherical lenses are optically perfect and of a small thickness.

The deduction of the optical laws governing the action of lenses of various shapes would require complicated computations; still, at least a general consideration of certain optical laws and facts should not be omitted in this treatise on phototopography, in order to better elucidate the formation of the optical images and to determine such elements of the photographic lens as will be needed in iconometric plotting.

Generally speaking, we meet with so-called simple lenses and with combinations or sets of lenses in photography. The symmetrical combinations are preferable for topographic surveying purposes, as they command a wider field or larger view

angle and as they are less affected with distortion and aberration than is generally the case with the simple or single lenses.

D. Optical Distortion.

So-called "spherical aberration" is more commonly produced by those light rays which pass through the marginal zone of the lens, as this part of the lens is less perfect than the central part. Spherical aberration may be reduced by decreasing the effective diameter of the lens which is generally done by inserting a so-called "diaphragm" between the lenses forming the combination, or by a reduction of the curvature of the faces of the lens.

Lenses corrected for spherical aberration are known as aplanatic lenses.

In so-called "chromatic aberration" the different color rays which compose the white light are unevenly refracted, and colored, ill-defined images are the result.

Lenses corrected for chromatic aberration are termed achromatic lenses.

Probably the greatest source of error introduced into photography is due to distortion of the image when using an inferior lens. It is caused primarily by the greater refraction—in the direction toward the optical axis—of those light-rays which pass through the marginal or border zones of the lens. When the image on the ground glass of a test-screen of the form shown in Fig. 78, Plate XLII, assumes the form indicated in Fig. 79, Plate XLII, so-called "pin-cushion distortion" has taken place, whereas an image of the form shown in Fig. 80, Plate XLII, is produced by "barrel-shape distortion." A lens affected by either is unfit for phototopographic purposes.

Commandant Moessard has invented an ingenious little contrivance—the tourniquet—by means of which the field or angle that is affected by distortion of the image may readily be determined experimentally.

Astigmatic distortion in an image is produced when well-defined images of the lateral points of an image may be obtained for two different positions of the ground-glass plate, and yet neither of these two images of the same points will represent the true shape of the original. Using a test-screen of the shape shown in Fig. 81, Plate XLII, radial distortion will be shown, Fig. 82, Plate XLII, for one position of the focusing-glass; the distortion will be in directions radiating from the center of the ground-glass plate. In the other position of the focusing-glass tangential distortion will be observed, Fig. 83, Plate XLII; the distortions will appear in directions at right angles to the directions radiating from the center of the ground-glass plate. Both radial and tangential distortions increase from the center toward the extraaxial zones of the lens.

Lenses corrected for astigmatic distortion are termed anastigmatic lenses.

The distortion shown in Fig. 84, Plate XLIII, of the image of the test-screen, Fig. 81, Plate XLII, is due to imperfect registering of two lenses composing a double lens; the component lenses are not "centered."

The Zeiss anastigmatic lens has a perfectly flat field. That is to say, if the ground glass has been focused for the sharp definition of a central point, extraaxial points will also be well defined on the focusing-plate.

Nearly all the older lens types were characterized by more or less curvature of the field, which means the focal length when focusing for a central point would be longer than when focusing for sharp definitions of a marginal point shown on the image plate.

E. Nodal Points and Nodal Planes of a Lens.

Formerly the thickness of a lens was disregarded when investigating its action upon light-rays passing through it and it was generally assumed that the central rays—those passing through the so-called "optical center" of a lens—suffered no change of direction.

Lenses are generally regarded as being bounded by two spherical surfaces. If both sides are convex (the lens is thicker in the center than at the edge) it is termed a biconvex or positive lens, Fig. 85, Plate XLIII.

If the spherical surfaces are concave on both sides of the lens (its center is thinner than its edge) it will be a biconcave or a negative lens, Fig. 89, Plate XLV.

Fig. 86, Plate XLIII, represents the cross-section of a concave-convex or a periscopic convex lens, the convex surface having a shorter radius than the concave surface, the lens being thicker at its center than at its margin. When the concave surface has the shorter radius the lens would be called convex-concave. The principal elements of a lens (Figs. 85 and 86, Plate XLIII) are:

First. The geometrical centers; they are the centers C and C_1 of the spherical surfaces forming the faces of the lens.

The line passing through C and C_1 is termed the principal axis of the lens.

Second. The vertices A and B of the lens are the intersections of the principal axis with the two spherical lens surfaces.

Third. The thickness AB of the lens is the distance between the vertices of the lens.

A lens is centered" when the plane PP, passing through the circumference of the lens—passing through the circular line of

intersection of the two lens surfaces—is intersected by the principal axis at right angles.

A lens-combination is centered when the planes PP_1 of the individual lenses are parallel and if they are intersected by the principal axis at right angles.

The foci of the separate lenses should also fall upon the principal axis or the images of the discs shown on the test-screen, Fig. 81, Plate XLII, will show so-called "flare spots," somewhat like those represented in Fig. 84, Plate XLIII.

A large flare spot, or halo, in the center of an image or picture may be produced by halation, caused by light-rays that have passed through the diaphragm aperture being reflected from the lens surfaces.

There exist certain relationships between the curvature of a lens, the distance of a luminous point from the lens, and the distance of its image from the lens which we will now briefly consider.

An incident ray SI, Fig. 85, Plate XLIII, will be refracted at I toward the radius R $(=C_0I)$, glass being a denser medium than air; it will continue through the lens in the direction IE, and the emergent ray EP will be parallel to the incident ray SI. The radii CI and C_1E are also parallel. The point C_0, where the refracted part IE of the light-ray intersects the optical axis of the lens, is known as the optical center of the lens and the following relation exists between its distances from the geometrical centers and the radii of the two lens surfaces:

$$\frac{CC_0}{C_1C_0}=\frac{R}{R_1}.$$

The triangles IC_0C and EC_0C_1 are similar.

Every lens has two nodal points N and N_1, Figs. 85 and 86, Plate XLIII, on the optical axis of the lens. The rays reaching the first nodal point N from luminous points S in space are parallel with the rays connecting the second nodal point N_1 with the corresponding images P of the luminous points.

Hence a negative produced by an optical-lens system may be regarded as a central projection or as a perspective image (the center of which coincides with the second nodal point N_1), Fig. 88, Plate XLIV.

The positions of the nodal points will be constant for all rays that make a small angle with the optical axis of the lens (for all rays passing through the small aperture of a diaphragm). The distances of the nodal points from the corresponding vertices of the lens are constants and their values are given by the equations (Fig. 85, Plate XLIII)

$$AN = \frac{AC_0}{n} \cdot \frac{CN}{CC_0},$$

$$BN_1 = \frac{BC_0}{n} \cdot \frac{C_1N_1}{C_1C_0},$$

where n is the refractive index from air into glass, or $n = \frac{3}{2}$.

As the distances of the nodal points from the optical center (C_0N and C_0N_1) will be small—they may sometimes become inappreciable or $=0$—we may omit the factors $\frac{CN}{CC_0}$ and $\frac{C_1N_1}{C_1C_0}$ from the equations (when $C_0N=0$ and $C_0N_1=0$ the factors $\frac{CN}{CC_0}$ and $\frac{C_1N_1}{C_1C_0}$ will become $=1$), hence

$$AN = \frac{AC_0}{n},$$

$$BN_1 = \frac{BC_0}{n}.$$

A close approximation to the distance between the nodal points will be

$$NN_1 = \frac{n-1}{n} AB.$$

The planes and the points of a lens system are numbered in the sense of the direction of the incident rays. With reference to Fig. 87, Plate XLIV, the light is supposed to be coming from the left, hence

$$
\begin{aligned}
N &= \text{first nodal point;} \\
F &= \text{first principal focus;} \\
FG &= \text{first focal plane;} \\
H_u NK &= \text{first nodal plane, whereas} \\
N_1 &= \text{second nodal point;} \\
F_1 &= \text{second principal focus, etc.}
\end{aligned}
$$

Lengths are considered plus, or positive, if they extend in the sense of the direction of the incident rays, and minus, or negative, if they extend in the opposite direction. With reference to Fig. 87, Plate XLIV, where the light comes from the left, we have

$$FN = -f \quad \text{and} \quad F_1N_1 = +f_1.$$

The nodal planes (passing through the nodal points and intersecting the principal axis at right angles) coincide with the principal planes if the extreme or outer medium of the optical lens system is the same, which is the case in photography where air surrounds the lens.

F. Principal Foci and Focal Planes of a Lens.

The principal foci F and F_1 of a biconvex or positive lens, Fig. 87, Plate XLIV, are two points on the optical axis—one on either side of the lens—where those incident rays converge which arrive at the refractive lens surface in a course parallel to the optical axis.

In Fig. 87, Plate XLIV, the ray $S'I^{IV}$, coming from a luminous point S' at infinite distance from the lens, traverses a path parallel in its course to the optical axis FF_1 of the lens, and

after refraction converges to the point F_1; while a similar ray PE'', coming from the opposite direction in a course parallel with the optical axis, converges to F.

The planes FG and F_1G_1, passing through the foci F and F_1 and intersecting the optical axis FF_1 at right angles, are termed focal planes.

G. The Focal Length of a Lens.

FN and F_1N_1, Fig. 87, Plate XLIV, are termed focal lengths and they are generally designated by the letter f. The value of the focal length is expressed by the equation

$$f_1 = -f = \frac{RR_1}{(n-1)\left(R_1 - R + \frac{n-1}{n} \cdot AB\right)}.$$

When this value for f_1 becomes *positive* it is an indication that the incident rays, when coming from infinite distance (parallel with the optical axis), are refracted to *converge* to the principal focus of the lens.

A *negative* value for f_1 would indicate that the rays entering the lens in a course parallel to its optical axis *diverge* from the principal focus.

For thin lenses (the distance between A and B, Fig. 85, Plate XLIII, is very small in comparison with the lengths of the radii R and R_1 and it may be assumed $=0$) the formula for the focal length would read

$$f = \frac{RR_1}{(n-1)(R_1 - R)}, \quad \text{or}$$

$$\frac{1}{f} = \frac{(n-1)(R_1 - R)}{R \cdot R_1} = (n-1)\left(\frac{1}{R} - \frac{1}{R_1}\right).$$

After substitution of $\frac{3}{2}$ for n, the approximate value for the refractive index of glass, the approximate value of the focal length for thin lenses would be

$$\frac{1}{f}=\frac{1}{2R}-\frac{1}{2R_1}.$$

H. The Biconvex or Positive Lens.

The image of a point at infinite distance from the biconvex lens is on the opposite side of the lens and falls together with its principal focus.

When the distant luminous point approaches the lens the image will recede, at first slowly, but more rapidly the nearer the luminous point advances toward the lens, and by the time the original point will have reached a distance from the lens equal to its double focal length, its image will have moved to a point beyond the lens, also at a distance of the double focal length. When the luminous point continues to approach the lens within the double focal distance range, its image moves faster and faster beyond the double focal distance on the opposite side of the lens, and when the luminous point finally falls together with the first focus (F) the image will disappear at infinite distance.

The relation which exists between the position of a luminous point (S) and that of its image (P) may be briefly expressed in the following equation:

$$\frac{1}{f}=\frac{1}{a}+\frac{1}{b},$$

where, with reference to Fig. 87, Plate XLIV,

f=principal focal length of lens;

a=distance ($SH=S_1N$) between the lens (its first nodal plane) and the luminous point (S);

b=distance (N_1P_1) between the lens (its second nodal plane) and the image plane PP_1.

From the above equation we deduce

$$a=\frac{f\cdot b}{f-b},$$

$$b=\frac{f\cdot a}{f-a},$$

$$f=\frac{a\cdot b}{a+b}.$$

With these simple formulæ any question concerning the distance between the image and the lens (its focal planes) may be solved.

We may have, for example, a lens of 15 cm. focal length and the object (the luminous point S, Fig. 87, Plate XLIV) may be 50 cm. away from the lens. It is desired to find the distance between the nodal and image planes (the distance P_1N_1).

For $f=-15$ and $a=-50$ we find,

$$\text{from } b=\frac{f\cdot a}{f-a},$$

$$b=\frac{15\cdot 50}{-15+50}=21.4 \text{ cm.}$$

I. Conjugate Foci and Conjugate Planes.

The image P_U, Fig. 87, Plate XLIV, of a luminous point U, situated on the optical axis of a biconvex or positive lens, will also be on the optical axis of the lens, but on the opposite side of the latter. The incident ray UI_U, emanating from the axial point U, will be refracted beyond I_U, and its course may be found by drawing a ray FH', parallel with UI_U, through the first principal focus F, which ray, after having traversed the lens, will emerge in a direction $H'G_U$, parallel to the direction of the optical axis. This fictitious or auxiliary ray $H'G_U$ intersects

the second focal plane F_1G_1 at G_U, and if we draw a line from K_U through G_U it will represent the path of the emergent ray originally emanating from U, and the intersection P_U of FF_1 with K_UG_U will locate the image P_U of the luminous axial point U.

The point U and its image P_U (when axial points) are termed "conjugate foci."

The planes T_UP_U and TU, both vertical to the optical axis and passing through the conjugate foci U and P_U, are termed conjugate planes.

K. To Find the Image of any Luminous Point for the Biconvex Lens.

The image T_U, Fig. 87, Plate XLIV, of any luminous point T in the conjugate plane UT may be found by locating the point of intersection T_U of the emergent rays of:

First, an incident ray $TI^{IV}M$, drawn parallel to the axis FF_1;

Second, an incident ray TN, drawn through the first nodal point N, and,

Third, an incident ray TF, drawn through the first principal focus F.

If the conjugate plane T_UP_U had already been located, the drawing of the third ray TF would suffice to locate the image T_U of T, as it is in the intersection of T_UP_U with the emergent ray $H'T_U$ of the incident ray TF.

Knowing how to locate the image P of any luminous point S or T for the biconvex or positive lens we can now locate the images of lines (as these may be regarded as a series of an infinite number of points), and also of surfaces (being composed of an infinite number of lines), provided the objects are not too far away from the optical axis of the lens.

The image P of any luminous point S, Fig. 87, Plate XLIV, not on the optical axis is found graphically by locating the point of intersection (after refraction) of the three following specific rays emanating from the point S:

First. Draw a ray from S through the first principal focus F and produce it to the intersection with the first nodal plane at K, whence it continues in a direction parallel to the principal axis (having passed through the first principal focus).

Second. Draw a ray from S parallel with the optical axis of the lens to its intersection H_1 with the second nodal plane, whence it converges to the second principal focus F_1 (having arrived at the lens in a direction parallel to its optical axis) and produce it to its intersection in P with PK.

Third. Draw a ray from S to the first nodal point N; it will pass through the second nodal point N_1, and it will emerge at E' in a direction $E'P$ parallel to the direction of the incident ray $SI'N$.

The image of any point S situated in a plane SS_1 perpendicular to the optical axis will fall within the conjugate plane P_1P.

In Fig. 90, Plate XLV, where similar points are designated by the same letters correspondingly used in Figs. 87 and 89, it has been shown how the image $P'P_1P$ of a line SS_1S' may be found if the incident rays are refracted by a biconvex lens.

The preceding definitions and formulæ are applicable only to light-rays which make small angles with the optical axis (for lenses with diaphragm stops), and they serve to illustrate and explain the formation of images.

More rigid (and consequently more complicated) formulæ would have to be applied to ascertain the best shape of lenses for special purposes.

L. The Biconcave or Negative Lens.

The biconcave or negative lens produces upright virtual images of originals which are beyond the principal plane, whereas the biconvex or positive lens, as has been shown in Fig. 90, Plate XLV, produces inverted real images of objects.

If the object UT, Fig. 91, Plate XLVI, is situated between

a positive lens and its principal focal plane FG, its rays will produce a virtual upright image $P_U T_U$.

Incident rays that are parallel to the optical axis of a positive lens will converge to the principal focus of the lens, but with the negative lens such rays will, after refraction, diverge in directions coming from the principal focus.

It will readily be seen, with reference to Fig. 89, Plate XLV, that the image PP_1 of an object SS_1 is upright and virtual. The paths of the light-rays are given in full lines and similar points are given the corresponding designation as in the preceding figures for the biconvex lens.

M. To Find the Image of a Luminous Point for a Biconcave Lens.

To find the image P of a luminous point S beyond the principal focal plane F_1G_1, Fig. 89, Plate XLV, three incident rays are drawn:

SI_1, parallel to the optical axis;

SI_2, through the principal point F;

SI_3, through the first nodal point N.

The intersection of the backward prolongation of the three corresponding emergent rays, PE_1, PE_2, and PE_3, will locate the image P of the luminous point S. These two points, P and S, are termed conjugate points, the same as mentioned for the positive lens.

N. Lens Combinations.

In Fig. 92, Plate XLVI, a combination of a single positive and one negative lens is shown. The positive lens may have:

$FN = F_1N_1 =$ focal length;

FG and $F_1G_1 =$ focal planes;

NM and $N_1H_p =$ nodal planes.

The negative lens may have:

$F'N' = F_1'N_1'$ = focal length;
$F'G'$ and $F_1'G_1'$ = principal focal planes;
$N'K$ and $N_1'L$ = nodal planes.

To find the principal focal planes of the lens combination we proceed in the same way as with a single lens, bearing in mind that the incident ray of the second lens is now the emergent ray of the first lens.

The line SI represents an incident ray arriving at the positive lens in a direction parallel to the optical axis; it is produced or continued in its course until it reaches the second nodal plane of the positive lens, where it changes its direction to one bisecting the second principal focus of this lens. In this direction it is again produced until it reaches the first nodal plane, in K, of the negative lens, whence it continues to the second nodal plane $N_1'L$ to the point L, the line KL being parallel to the optical axis.

Now we draw through the first principal focus F' of the negative lens the auxiliary ray YF' parallel with HF_1. YX, drawn parallel to the optical axis, intersects the second focal plane $F_1'G_1'$ of the negative lens in X, and XL will be the direction of the final emergent ray; its intersection F_1'' with the optical axis is the second principal focus of the lens combination.

This point, F_1'', may be checked with a second incident ray S_1I_1, and $F_1''G_1''$ will be the second principal focal plane of this lens combination.

In a similar manner two incident rays PI' and P_1I_1' arriving at the negative lens from the other side of the combination, under a direction parallel to the optical axis, will locate the first principal focal plane $F''G''$ of this lens combination.

The first nodal plane of this combination ($=N''\alpha\beta$) is located by determining the intersections α and β of the original incident rays PI' and P_1I_1' with the final emergent rays $F''T$ and FT_1 respectively.

The second nodal plane of this lens combination is fixed by

the intersections of the original incident rays SI and S_1I_1 with the final emergent rays $F_1''X$ and $F_1''X_1$ respectively.

O. Diaphragms or Lens Stops.

It had already been mentioned incidentally that diaphragms are used to reduce the aberrations of light-rays which arrive at the marginal zones of a lens, by excluding them from action upon the photographic plate.

By selecting a sufficiently small aperture in the diaphragm all rays may be excluded from reaching the interior of the camera, which make an angle with the optical axis larger than the angle controlling the limit of the central field of the lens that may be regarded free from distortion.

This would comprise that effective circular disc of a lens for which the preceding optical laws and rules have been given, as the conditions are different for the extra-axial zones of a lens, and those rules are not applicable to the latter. The laws given in the preceding pages become less and less true the nearer the outer margin of the lens is approached.

By the insertion of a diaphragm stop, a more or less great amount of light will be excluded from action upon the sensitized film of the photographic plate, and the smaller the aperture in the diaphragm the longer the exposure will have to be made in order to reduce a given amount of silver in the sensitized film.

Generally speaking, the quantity of light admitted into the camera will be proportional to the square of the diameter of the diaphragm aperture.

P. Rapidity of a Lens.

Lenses with comparatively short focal lengths will produce brighter images than such with long focal lengths, the brightness of the image being inversely proportional to the square of the focal length. The more light is allowed to enter the camera the

quicker the reduction of the chemical compounds of the sensitized film will take place; the rapidity of a lens depends in a great measure upon the quantity of light which the lens will suffer to reach the plate.

Small apertures necessarily will permit more light to reach the central part of the plate than reaches its extra-axial parts, and photographs obtained through small diaphragm apertures often are darker and lack good definition on the edges.

If the sensitive plate could be made less sensitive to the action of the light in its central part than it is on the edges this drawback would be overcome, in a great measure at least; practically, however, the sensitized coating is of a uniform character.

If d represents the diameter of the diaphragm aperture, and if f represents the focal length of the lens, then the rapidity of the lens (or the brightness of the image produced with that lens) will be proportional to the fraction

$$\left(\frac{d}{f}\right)^2.$$

Q. Length of Exposure.

Generally speaking, the length of exposure that should be given a plate is inversely proportional to the rapidity of the lens, hence proportional to the fraction

$$\left(\frac{f}{d}\right)^2.$$

R. Distortion Produced by Diaphragms.

When a diaphragm is placed in front of a positive lens so-called "barrel-shape" distortion (Fig. 80, Plate XLII) frequently ensues in the border regions of the image, and a diaphragm placed behind the lens is apt to produce so-called "pincushion" distortion (Fig. 79, Plate XLII). It has been sought to compensate

these distorting effects by using two lenses and inserting the diaphragm between them.

S. Chromatic Aberration of Light-rays.

The researches of Dolland, made with a view to reduce or overcome chromatic aberration of telescopic lenses, led to the combination of different glass compounds in the same lens, or better, to the combination of two or more lenses each of which was made of a glass mixture of different but well-known qualities regarding both dispersoin and refraction. He was successful in thus eliminating from the old-style lenses the greater part of the chromatic aberration which shows itself in the more or less pronounced appearance of colors on the borders of an image with a simultaneous indistinctness of outline.

The improvement in this respect of all modern photographic lenses is principally due to the results obtained in the optical factory of Zeiss in Jena, where extensive experimental researches were made by Dr. Schott by direction of Prof. Abbe. By a judicious selection and combination of the glasses obtainable from the works at Jena, opticians can now produce lenses more fully answering the different requirements for the various uses to which photography may be applied than has heretofore been deemed possible.

Still, so-called achromatic photographic lenses cannot yet be made free from *all* chromatic aberration, as no two kinds of glass have yet been compounded to precisely counteract or neutralize the refractive errors inherent to each.

That amount of aberration with which so-called achromatic lenses still remain affected is known as secondary chromatic aberration. It has been reduced to such a degree that its disturbing effect in achromatic telescopes—where small angles of the field are only used—disappears altogether, but in lens combinations for photographic work, and particularly in phototopography (where large field angles are used), this permanent defect

is still seriously felt, particularly when short focal lengths of the camera-lenses become desirable.

Achromatic photographic double lenses are composed of two or three lenses each, the glass of the single lenses being carefully selected with a view towards overcoming the chromatic aberration of the light-rays as much as possible.

So-called white or colorless light is composed of a series of colored light-rays intermingled in such a way that their joint effect is that of colorless light. The main characteristic of these color rays with reference to our subject is "each of the different light-rays that form the component parts of white light has a different refractive index for the same medium;" or, light-rays of different colors will be refracted under different angles for the same refractive medium. Red rays, for example, are less refracted than yellow rays, and these again are less refracted than the blue and violet light-rays for the same refracting medium.

If a pencil of white light be intercepted by a glass prism it will become separated into its component color rays; each different color, representing a different wave-length, is differently refracted by the prism, each color having its own special index of refraction.

The prism separates and disperses the different color rays which compose the white light, and when the refracted rays are cast upon a white screen in a dark-room, the band of colors appearing on the screen is termed the spectrum of the particular light used.

If a pencil of sunlight had been used in the experiment the solar spectrum would appear on the screen and the red rays will be less refracted than the orange, the green, the blue, and the violet rays.

We had seen (Fig. 77, Plate XLI) that a biconvex lens may be regarded as a series of concentric prismatic rings, one superimposed upon the other, and it will be evident that a chromatic lens will retract red rays less strongly than the orange, green, or violet rays. The lens will have a shorter focus for the violet

and blue rays than it has for the orange or red rays, and the focal length of such a lens will vary according to the particular color of the emergent ray (Fig. 93, Plate XLVII).

As the retina of our eye is more sensitive to the yellow and green light rays than to those of another color, we will, when focusing upon a landscape view, perceive the best definition when the focusing-plate falls together with the focal plane of the lens focus for the yellow or light-green light-rays.

Generally speaking, however, the ordinary photographic dry-plate emulsion is less sensitive to yellow light and more sensitive to blue or violet light-rays, and in order to obtain a good negative, the plate should be exposed in the focal plane of the blue or violet light-rays instead of being exposed in the focal plane of the yellow rays, as it would be if exposed in the position as determined with the ground glass for the best ocular definition.

The distance *D*, Fig. 93, Plate XLVII, between the focal planes of the yellow rays (active rays optically or visually) and the blue-violet (or chemically active) rays is termed the chromatic aberration or variation of the rays. Lenses affected with chromatic aberration have a chemical focus, differing more or less from the optical or visual focus, according to the more or less great amount of chromatic aberration by which the lens may be affected.

Compositions of glass of different indices of refraction will separate white light into spectra of different lengths. Lenses made of glass having a small refractive index will show a small difference in the focal variation *D*, Fig. 93, Plate XLVII (between the focal lengths), of the red and violet light-rays. Such glass is generally known as crown glass and its index of refraction is from 1.5 to 1.6.

Lenses made of a composition of glass having a strong refractive power will show a greater focal variation. Such glass is known as flint glass and its index of refraction is from 1.6 to 1.9.

Any crown-glass positive lens of a given focal length may

be matched with a flint-glass negative lens of a larger focal length (Fig. 92) that may be of such a refractive power to bring the chemical focus of the combined pair almost into coincidence with the optical or visual focus without annulling the entire refractive power of the positive lens. A lens combination of this character which still retains the characteristics of the positive lens (positive focal length and real image of a distant object) and which is almost free from chromatic aberration is termed an achromatic lens combination.

CHAPTER VIII.

PHOTOGRAMMETERS OR PHOTOGRAMMETRIC INSTRUMENTS.

PHOTOGRAPHIC surveying instruments have already undergone many changes and various patterns are in use in different localities. Until quite recently photogrammeters were not procurable in open market. Nearly every observer who made use of the photographic method for topographic surveys had an apparatus constructed especially for his particular needs and according to his personal ideas. Thus we find:

First. The ordinary photographic field camera (with bellows extension) converted into a surveying camera by a few simple additions and mechanical modifications.

Second. A specially constructed surveying camera with a constant focal length and special devices for leveling (to bring the sensitive film into vertical plane).

Third. A surveying camera combined with some geodetic surveying instrument (with a surveyor's compass, a transit, or with a plane table). Such combination may be permanent, or it may be effected in such a way that the camera is detachable and both may be used independently and separately.

The practical value of a photogrammeter depends largely upon the quality and general uniformity of the lens or lens combination upon the rigidity of the component parts of the apparatus, its transportability, and upon the rapidity with which it may be adjusted and placed in position for use.

The principal lenses that have been employed for phototopographic purposes are Dallmeyer's rapid rectilinear, Steinheil's aplanatic, Busch's pantoscopic, Görz's double anastigmatic, Voigtländer's collinear, and more recently Zeiss's anastigmatic lens.

The nodal points, the focal length, the arc of visibility, and the arc which is perfectly free from distortion of any kind should be known for every lens used for phototopographic purposes, and the manufacturers of lenses of good quality are best fitted to determine these values with great precision.

General Requirements to be Fulfilled by a Topographic Surveying Camera.

A good surveying camera or photogrammeter for topographic work should produce negatives that are geometrically true perspectives. The elements of the latter should be known and the following desiderata should be fulfilled:

First. The photographic plates should be adjustable in vertical plane.

Second. The distance between nodal and image plane should be maintained unchanged for all exposures.

Third. This distance—the constant focal length—must be known, or will have to be determined for every instrument.

Fourth. Means should be provided to trace the horizon line (line of intersection of the horizon plane with the vertical photographic plate) upon every negative.

Fifth. Means should be provided for locating the principal point (the point of intersection of the horizontal optical axis of the camera with the vertical sensitive plate) upon every negative.

Sixth. A ready orientation of the photographs for iconometric plotting should be possible; and we may add as

Seventh. Enough characteristic stations (outside of the triangulation scheme) are to be occupied with the camera to give a full development of the terrene, which is to be mapped.

I. Ordinary Cameras (with Extension Bellows) Converted into Surveying-cameras.

These surveying-cameras have been constructed primarily for economical reasons and their use should not be extended beyond preliminary work or beyond surveys made for experimental study. For extensive use the results will not be sufficiently uniform and accurate.

Such cameras are generally supported by three leveling-screws upon a tripod and they are provided with a circular level *l*, Fig. 95, Plate XLVIII, or with two cross-levels *L*, Fig. 94, Plate XLVII, for adjusting the sensitive plate into vertical plane. The distance between nodal plane and photographic plate is made invariable, generally by means of two metal rods *R*, as shown in Fig. 94, Plate XLVII (Werner's apparatus made by R. Lechner in Vienna, Austria).

In Fig. 95, Plate XLVIII (apparatus of Dr. Vogel and Prof. Doergens, made by Stegeman in Berlin, Prussia), this has been accomplished by means of the clamp *M*. After the bellows have been extended sufficiently to establish the desired focal length, which may be read off on the vernier *n*, the screw *M* is securely clamped. The pinion *K* with rack movement *zz* serves to give the needed slow motion (when extending the bellows) to set the vernier *n*.

Dr. G. Le Bon also used a modified field camera for his archæological researches in India, which were carried on under the auspices of the French Ministry of Culture.

The braces *H* in Fig. 95, Plate XLVIII, and *R* in Fig. 94, Plate XLVII, give the plate receivers a vertical position upon the level extension boards.

The short brass points *m* in Fig. 95, Plate XLVIII, locate the principal and horizon lines by their reproduction on the negatives. They are brought into actual contact with the plate (before exposure) by turning the buttons *h*, thus producing a sharp image of their outlines on the margins of the negatives.

Fig. 96, Plate XLVIII, shows an arrangement for setting the four teeth (which locate the horizon line hh_1 and the principal line vv_1 on the negative) close against the sensitive film surface, which has been used a great deal in Germany. By turning the arms *r* the teeth may be brought into direct contact with the plate, and when the camera should be used to obtain pictures for their pictorial value only the teeth may be removed from the plate by turning the buttons *a*, *b*, *c*, and *d* back.

The original Coast Survey Camera was provided with a device which would operate all four teeth together by turning but one button.

II. Special Surveying-cameras with Constant Focal Lengths.

Among the numerous patterns of this class of instruments that devised by Dr. Meydenbaur is probably the earliest form.

A. Dr. Meydenbaur's new small Magazine Camera.

This instrument is represented in Figs. 97 and 98, Plate XLVIII. The camera weighs 750 grams and the plates are 9×12 centimeters in size. The camera-box is mounted, by means of ball-and-socket joint, upon a vertical rod which is joined at the bottom to three short legs in such a way that the four pieces may be folded together to form a stout cane 0.85 m. long. The lower ends of the three legs of this tripod and the upper end of the supporting staff are connected by twisted violin-strings. Tension may be given them by turning the ratchet-wheels indicated in Fig. 98, Plate XLVIII, thus producing a very light and yet rigid tripod. The plates contained in the magazine *M*

are exposed successively by being pressed against a metal frame having marks indicating the principal and horizon lines. This frame is securely fastened at a constant distance from the lens, establishing the constant focal length of the camera. Each plate, after exposure, may be dropped into the leather pouch *b*, Fig. 98, Plate XLVIII, secured underneath the camera, by manipulating a button *a'*. The leather pouch, together with one dozen plates, weighs about 500 grams. Dr. Meydenbaur has used a pantoscopic lens, made by E. Busch in Rathenow, Prussia, which is said to produce geometrically correct perspectives of an angular field of 105°. A circular level *L* serves to adjust the plates into vertical plane before exposure, using the ball-and-socket joint for this purpose.

B. Capt. E. Deville's Surveying-camera (new Model).

The following description of Capt. E. Deville's new surveying-camera is taken from Deville's "Photographic Surveying," second edition (1895). The camera is shown in Fig. 99, Plate XLIX, and Fig. 100, Plate L; Figs. 101 and 102, Plate LI, represent sections of the instrument.

The camera proper is a rectangular metal (aluminum) box *AB*, Figs. 101 and 102, Plate LI, open at one end. It carries the lens *L* and two sets of cross-levels *CC*, which may be read through openings in the outer mahogany casing. The metal box is supported in the wooden casing by wooden blocks and by a wooden frame FF_1 held in position by two bolts *DD*.

The plate-holder is made for single plates; it is inserted into the carrier *EE*, which may be moved forward and backward by means of the thumb-screw *G*.

A folding shade, of wood, *HH*, Figs. 101 and 102, Plate LI, hooked to the front of the camera, and diaphragms *KK* inside of the metal box, intercept all light-rays which do not contribute to the formation of the image on the photographic plate.

The camera rests on a triangular base, Fig. 103, Plate LI, with foot-screws, in shape exactly like the base of the transit theodolite which is used in conjunction with Deville's surveying-camera, so that either instrument may be placed on the same tripod at any station. The camera may be set up on the tripod with either the long or the short side vertical.

Both transit and tripod are carried by the surveyor, and one camera including one dozen plates (in the single holders) without a tripod are taken by one of the men who always accompany the surveyor as packers. The assistant has a second camera with plates and a separate tripod.

The legs of these tripods when folded together are twenty inches long. They are placed in separate cases and one is carried under the box of the transit, to be carried on the back of the surveyor, and the other is attached to the sole-leather case of the camera in charge of the assistant surveyor.

The lens of this camera is a Zeiss anastigmat, No. 3 of series V, 141 mm. focal length, with a deep-orange color-screen in front.

Having mounted the camera on the tripod, the plate-holder carrier *E* is moved back as far as it will go by turning the screw *G*, Figs. 101 and 102, Plate LI; the plate-holder is inserted through the opening *M*, the slide is withdrawn, and the carrier moved forward by revolving the screw *G* until the plate is brought into contact with the back of the metal box *AB*. In order to secure a perfect contact, the carrier *E* has a certain amount of free motion. The camera should now be turned in the proper direction; the field embraced by the plate is indicated by lines drawn on the outside of the mahogany casing. The camera is then carefully leveled, the exposure given, and the plate-holder is withdrawn by repeating the same operations in the inverse order as described for its insertion.

For the sake of rigidity and to reduce the number of adjustments to be made in the field to a minimum, the levels *CC* have been fixed rigidly to the metal camera-box (without any device for subseqeunt adjustment). They are, however, very closely

adjusted by the maker of the instrument. For this purpose he takes the metal camera-box out of the mahogany casing and deposits the same on a piece of plate glass which previously had been leveled like an artificial horizon. By filing down one end or the other of the levels' outer case, each bubble is brought as near to the middle of its tube as possible. The graduation on the latter is numbered continuously from end to end, as illustrated in Fig. 104, Plate LI.

Each camera is accompanied by a piece of plate glass $\frac{1}{4}$ inch thick and 11 inches long, which can be inserted into the carrier in place of the plate-holder. That end of the glass plate which projects beyond the camera limits when it is thus inserted is coated on the back with a varnish composed of gum guaiacum dissolved in alcohol to which some lampblack had been added. This coating has very nearly the same refractive index as glass and is well adapted for precluding all reflections from the back of the glass plate.

After the camera has been received from the maker the exact readings of the levels, when the back of the metal box—against which the photographic plate is pressed—is vertical, should be ascertained. To do this, the bolts *P*, Fig. 102, Plate LI, next to the opening *M*, are loosened and removed. *Q* may then slide backwards and be taken out. The piece of plate glass is now inserted in the carrier *E*, Figs. 101 and 102, Plate LI, and pressed into contact with the metal box. The camera is placed on its tripod and leveled. Immediately in front and at the same height a transit (or a leveling instrument) *T*, Fig. 105, Plate LI, is set up, and after carefully adjusting it, a distant point *P* is selected on the same level with the transit and camera. The intersection of the cross-threads in the telescope is brought to coincide with *P*, and the telescope is clamped to the vertical circle. Turning it around in azimuth, the image of *P*, reflected by the plate glass, should appear in the intersection of the telescope's cross-threads. If it does, the face of the plate glass is vertical and the position of the bubble in the tube of the level,

directed at right angles to the plate glass, is the correct one for adjusting the instrument in the future. If it does not, the camera must be tilted forward or backward by means of the foot-screws until coincidence is established. The middle of the bubble of the level may or may not now be in the middle of the tube, but its position, whatever it is, will be the correct one for adjusting the camera in its subsequent use. The divisions of the graduation between which the bubble rests should therefore be ascertained and the middle reading be recorded, and whenever the camera is to be leveled, it must be remembered that the middle of the bubble is to coincide with the recorded middle reading.

This determination of the level-reading is to be made for the two positions of the camera in which it is used (horizontal and vertical position).

1. Determination of the Focal Length, the Horizon Line, and the Principal Line.

The next step is to fix the position of the principal point on the photographic plate and to ascertain the length of the distance line. Select a station so that a series of distinct and well-defined distant points may be found on the horizon line as it is laid down by the maker of the camera. The selected view may comprise the distant shore line of a lake, a large building or a row of buildings. Set up the tripod and adjust the transit. Find two points E and F, Fig. 106, Plate LII, on the horizon line (with a zenith distance of 90°) that both come within the field of the camera, when set horizontal, and fall near the two vertical edges of the plate. Measure the horizontal angle ω between them. Find two other points G and H, also on the horizon line and such distance apart that both come within the field of the camera when the same is set up vertical. Now replace the transit by the camera in the horizontal position and turn it so that E and F will appear within the limits of the plate, level

carefully, and expose the plate. Set the camera in the vertical position and turn it in azimuth to take in G and H, level carefully, and expose another plate.

The first plate, after development, shows the two points E and F on a line very nearly parallel to the edges AB and CD, Fig. 106, Plate LII, of the metal box. The principal point, of course, will be on this line, which is cut into the film, using a fine needle point and straight-edge for this purpose.

The second plate, exposed in the vertical position of the camera, will give another horizon line GH, which may be transferred to the first plate by means of the distances AK and CL to the corners of the metal box. This (principal) line is likewise cut through the film of the photographic plate with a fine needle point and straight-edge. The principal point P will be at the intersection of these two horizon lines EF and GH.

The length of the distance line ($SP=f$), or the focal length of the camera, may be computed from the horizontal angle ω, included between SE and SF, together with the distances $EP=a$ and $PF=b$.

Let S, Fig. 107, Plate LII, be the second nodal point of the camera-lens, α and β the angles ESP and PSF, when

$$\alpha+\beta=\omega.$$

The lengths of a and b are measured directly on the plate. If we designate the focal length PS by f we have:

$$\tan\alpha=\frac{a}{f},$$

$$\tan\beta=\frac{b}{f},$$

$$\tan\alpha\times\tan\beta=\frac{ab}{f^2}.$$

Hence

$$\tan(\alpha+\beta)=\tan\omega$$

$$=\frac{\frac{a}{f}+\frac{b}{f}}{1-\frac{ab}{f^2}},$$

or

$$f^2-\frac{a+b}{\tan\omega}f-ab=0.$$

Resolving this adfected quadratic equation we find

$$f=\frac{a+b}{2\tan\omega}+\sqrt{\frac{(a+b)^2}{4\tan^2\omega}+ab}.$$

Having now found the focal length and the principal point, reference marks should be made on the edges of the metal box to indicate the horizon and principal lines as well as the focal length on the prints from the negatives.

Measure the distance m, Fig. 106, Plate LII, from P to AC. From the corresponding corners A and C, Fig. 108, Plate LII, of the metal box lay out m on AR and on CT. With a very fine and sharp file, held in the direction toward the lens, cut into the edge forming the rear frame of the metal box a clean and sharp notch at T and another at R.

Repeat the same operation from the corners A and B with the distance n from P to AB.

The lines OQ and RT will be the horizon and principal lines of the photographs, when the camera has been leveled to bring the bubble into its proper position as mentioned in the foregoing.

From R and T measure the distances Rr, Rr', Tt, Tt', equal to one half of the focal length $\left(=\frac{f}{2}\right)$. From O and Q measure Oo, Oo', Qq, Qq', equal to one quarter of the focal length, and at each one of these points make another notch with the file

held in the direction of the lens. Every photograph will now show twelve triangular projections reaching into the dark border of the photograph. Four of these projections serve to fix the horizon and principal lines; the remaining eight give the focal-length value.

2. Adjustment of Camera Spirit-levels.

It now remains necessary to find the correct readings of the transverse levels (placed parallel with the sensitive plate) when the horizon and principal lines pass exactly through their corresponding notches of the metal box.

Set up the camera again, facing the same distant view as before, but in adjusting it bring the bubble of the transverse level near one end of the tube; note the reading of the level-tube graduation and expose a plate. When developed, it will give a horizon line *EF*, Fig. 109, Plate LII, cutting the border of the negative in *A* and *B*, at some distance from the pictured notches *O* and *Q*. Now change the adjustment of the camera by bringing the bubble of the transverse level to the other end of the tube, note the reading of the level and expose another plate. This when developed will give another horizon line *N′F′*, cutting the border of the negative in *C* and *D*.

Great care should be exercised in both cases to keep the other level (the one at right angles to the sensitive plate) at its proper reading, in order to expose both plates while in vertical plan.

After measuring *CO* and *OA* or *BQ* and *QD*, a simple proportion gives the proper reading of the transverse level which will bring the horizon line of the vertically exposed plate through the two notches *O* and *Q* of the metal box.

The correct reading of the transverse level of the second set of levels is found by the same method, with the camera in the vertical position.

All these operations must be executed with great care and precision (and with the help of a microscope of moderate power),

as the subsequent iconometric plotting of pictured points is based upon the determination of the ordinates and abscissæ of such points, on the pictures, with reference to the principal and horizon lines which serve as a system of rectangular coordinates.

It had been assumed that the levels were placed very nearly in correct adjustment by the maker as mentioned before. If found too much out, they must, of course, first be approximately adjusted by setting the metal box on a well-leveled plate. For this purpose the plate glass supplied with each camera may be set on the camera base and leveled like an artificial horizon.

3. Use of the Instruments Comprised in the Canadian Phototopographic Outfit.

The instruments and tripod of the Canadian instrumental outfit being very light, steadiness may be secured by means of a net suspended between the tripod legs, into which a heavy weight (rock) is placed. With this device, photographs of good definition and better observations may be obtained than without it, and there is no risk of the instruments (secured to the tripod) being blown over during one of the sudden and strong gusts of wind so frequently encountered on elevated and exposed mountain peaks.

After the phototopographer has arrived at a triangulation station he adjusts the transit and observes the azimuths and zenith distances of all signals (marking the triangulation points and camera stations already occupied) in the vicinity that may be visible from his position. If accompanied by his assistant, each reads one vernier and records the readings independently of the other into separate record books. After the observations at that station have been completed the two surveyors compare notes and any discrepancy that may be discovered in the recorded data is corrected on the spot by a careful repetition of the doubtful observations.

The Canadian camera is carried in a sole-leather case which also contains twelve filled double plate-holders; when more

holders are needed for a day's work they must be carried in a separate receptacle. Taking the camera from its case the leveling base, Fig. 103, Plate LI, is secured to it by means of the central clamp-screw, and the camera is then placed upon the tripod (from which the transit had been removed) without disturbing the position of the latter.

The shade or hood *H*, Fig. 99, Plate XLIX, is now unfolded and attached to the hooks at the front of the camera. A plate-holder is inserted into the carrier and the number of the plate, in position to be exposed, is noted upon a rough outline sketch of the panorama views (commanded by the field of the camera image as indicated by the converging lines cut into the exterior sides of the camera-box), entering also such notes as may be of value for the subsequent development of the plate, for the iconometric plotting of the topography photographed upon the latter, or for the lettering of the finished map.

Having made sure that the cap is secure on the lens, the slide is withdrawn from the plate-holder and the sensitized surface of the plate is brought into direct contact with the frame of the metal box by turning the screw *G*, Figs. 101 and 102, Plate LI, devised for this purpose. The surveyor next turns the camera in azimuth until the lines on the upper face of the wooden casing show that it is properly directed, or oriented, to include the panorama section to be photographed between the lines. The field of view should, of course, in each case coincide with the outline sketch bearing the number of the plate in position to be exposed. Sighting along the lines (up and down) shown on the side face of the wooden camera casing, the observer can assure himself whether the view on the image plate reaches high or low enough to control the landscape; if it does not, he either puts the longer dimension of the camera upright, or, if already in that position, he may have to occupy a secondary camera station, either above or below the one occupied, as the case may be.

The observer next levels the camera carefully in the manner

previously described and exposes the plate. Whenever the sunlight appears inside of the front hood, the latter should be shaded off during the exposure of the plate by holding some object (plate-holder slide or hat) above the hood. Under no circumstances must the sun be allowed to shine upon the lens.

Every evening after the return to camp the surveyor replaces the exposed plates (in the dark-tent) by new ones, using a ruby-colored light for this purpose. He also marks the exposed plates in one corner close to the margin, before removal from the holder, with his initials, with the number of the dozen and number of plate, using a soft-lead pencil for this purpose. N. N.—IV—5, for instance, means plate No. 5 of the fourth dozen and exposed by N. N. This would be the forty-first plate exposed in that season.

The exposed plates are placed into a double tin or copper box, Fig. 110, Plate LII, which can be closed hermetically and which will float when filled with two dozen plates (should it be accidentally thrown into water by the capsizing of a canoe). These boxes, as soon as filled, are shipped to the head office in Ottawa, where the plates are developed by a specialist.

The data obtained by aid of the transit theodolite for triangulation purposes are recorded in the field-books in the manner customary for such work.

The horizontal angles observed with the transit (or altazimuth) to the terrene points (so-called "reference points") marked on the outline sketch, which should accompany each negative, serve not only for the orientation of the horizontal projection of the plate on the working-plan—to "orient" the so-called "picture trace"—but they also aid materially to ascertain the amount of (and to counteract in a measure) the distortion of the paper prints or photographic enlargements. The vertical angles, together with the plotted distances to such reference points, serve to check and verify the position of the horizon line on the different photographs as given by the camera alone.

Important camera stations are occupied by the surveyor,

secondary stations by the assistant with a separate camera. No trigonometrical observations are made by the assistant when occupying secondary and tertiary camera stations, as he is not supplied with a transit. The surveyor locates such stations by observing upon the signals, erected by the assistant before leaving the station, from his own stations, and he subsequently computes their positions as "concluded points." All views are taken with the same stop, *f*/36.

C. The U. S. Coast and Geodetic Survey Phototopographic Cameras.

In the preceding we have already referred to the desirability that phototopographic surveying instruments designed for use in rough mountain districts, where transportation facilities are restricted and generally confined to portage over rough trails (or to transportation up steep mountain sides on the backs of packers), should be made as simple as possible to indefinitely remain in perfect adjustment.

The phototopographic party generally reaches the mountain station, after an exerting climb of several hours, in a more or less fatigued condition, and to obtain the best results the observer should not be required to spend much time in assembling and adjusting the instrument before the actual survey work may be begun. Then, too, the atmospheric conditions are rarely stable for any length of time, making it most desirable to utilize favorable conditions at once. The fields of labor in S.E. Alaska, where the Coast and Geodetic Survey camera work has been done, are peculiarly well adapted for the application of the phototopographic methods, on account of the prevailing cloudy condition of the atmosphere in the higher altitudes. Distant peaks and mountain groups, without apparent warning, become suddenly shrouded in drifting mists, which soon gather into a thick cloud stratum, shutting the mountains out from view for days and weeks at a time. During the summer months the prevailing southerly, vapor-laden winds drifting inland from the Pacific Ocean find their moisture condensed on approaching the snow-

and ice-fields or hanging glaciers in the higher altitudes. Clear days are generally accompanied by calms or they occur when a northerly drift in the air-currents prevails.

Phototheodolites or instruments in which the elements of a transit and a camera are assembled into a single apparatus, all parts being merged into a composite instrument, to remain united during the various operations of observing and plate exposures, mostly have the objectionable feature of unstable adjustments, requiring frequent tests and readjustments of their component parts. They are, furthermore, more or less cumbersome and heavy, making them more liable in transportation than instruments that may be divided into two or three parts (each section being complete in itself) and carried by two or three helpers.

The original type of the U. S. Coast and Geodetic Survey camera, used in connection with the topographic reconnaissance made in S.E. Alaska under the U. S. Alaskan Boundary Commissioner, was similar in form to Capt. Deville's original surveying camera, except that it was provided with a separate tripod with ball-and-socket adjustment and that the teeth or index marks which serve to fix the principal and horizon lines on the negatives could be pressed into direct contact with the sensitized film of the photographic plate simply by turning a button after withdrawal of the slide. This camera was provided with a ground glass, enabling the observer to inspect the entire field controlled by each plate before exposure was made.

The camera proper was a plain rectangular box, made of well-seasoned mahogany, $6\frac{3}{4}\times6\frac{5}{8}\times9\frac{1}{4}$ inches in size. It was always used in the same position, with the short faces vertical. A circular level attached to the upper camera side served for leveling the instrument, bringing the photographic plate into vertical plane.

The bamboo tripod legs were made in three sections, each sixteen inches long and screwed together at the joints. When dismembered, the tripod was carried in a sole-leather case or

knapsack, together with the camera, six double plate-holders, note-book, barometer, etc. A yellow color screen could be attached to the inner side of the camera-box just behind the lens mount. The four-inch transit used in conjunction with this camera had a separate tripod.

With a view toward simplicity in structure and a light weight to be transported in the mountains, the new Coast and Geodetic Survey phototopographic instrument has been made into three distinct parts or sections, the transit, the camera, and one tripod, serving for both.

The superstructure, embracing the Y's, telescope, and vertical circle, may be lifted off the horizontal circle, to which it ordinarily is secured by two capstan-head screws, uniting the base-plate of the Y support with the vernier plate of the horizontal circle. Plate XCVIII shows the transit as used for trigonometric observations.

The camera, complete as such, may be mounted on the vernier plate of the horizontal circle with the same capstan-head screws that secure the superstructure of the transit. Plate XCIX shows the camera-theodolite in its usual position (long sides of the photographic plate horizontal). The truncated aluminum cone under the camera-box is secured to the latter by means of a central clamp-screw (within the hollow cone), and the base-rim of the cone is then fastened to the vernier plate of the horizontal circle with the two capstan-head screws already mentioned.

Both transit and surveying camera are used on the same tripod. The understructure (with the horizontal circle) is connected with the tripod by means of the triangular tripod plate shown in upper part of Plate XCIX. This triangular plate is screwed to the tripod and the three leveling-screws of the understructure are placed on the arms of this plate, a clamp device securing the conical ends of the leveling-screws to the tripod plate serves to prevent a possible disturbance of the understructure when the exchange from transit to camera is made.

The adjustments of transit and camera are stable and with ordinary care will suffer no frequent changes. To reduce weight aluminum has been used when practicable without sacrificing rigidity and strength.

The camera is packed in a stout packing-case, together with eight double plate-holders, focusing-cloth, note-book, etc. The transit is packed by itself.

A small triangular net or hammock, that may readily be attached to the legs, should be provided when stations are occupied in windy weather. These light instruments lack stability, but by placing a suitable weight (a rock will do) in the net suspended between the tripod legs no noticeable vibration will occur.

The inner edge of the rear frame of the inner (aluminum) camera-box is supplied with notches to mark the horizon and the principal lines. The constant focal length (about $5^{31}/_{32}$ inches) of the lens is also laid off on the inner edge of this rim, one half to either side of the principal line and one half to one side of the horizon line. All these notches will be printed on the edges of the negatives, giving ready means for checking distortions in the prints.

As will be noted, this camera-box is similar in form to Capt. Deville's new model, having also the same lens (Zeiss anastigmat, $6\frac{1}{2}\times 8\frac{1}{2}$, series V). The plates used in this camera are 5×8 inches. The outer box or casing is made of well-seasoned $\frac{1}{4}$-inch mahogany reinforced with strips of brass. The sensitized film of the photographic plate may be brought into direct contact with the rear frame of the inner camera-box by means of a milled-head screw attached to the front board of the outer box with a counteracting spiral spring similar to *G*, Figs. 101 and 102, Plate LI.

The lens is about $2^{1}/_{16}$ inches from one long side and $3^{15}/_{16}$ inches from the other long side of the outer wooden case, making the horizon line correspondingly nearer one long side of the camera. When the main field of the terrene falls below the station the camera is mounted with the lens *low* and *vice versa*

Three sets of cross-levels are attached to the inner camera-box, each being covered with a glass window inserted into the outer wooden case, so that a set of cross-levels will appear on the upper camera side for each of the three positions in which the camera may be mounted. Plate C shows the vertical position of this camera; it is used when the terrene to be pictured subtends rather large vertical angles for both elevation and depression.

D. L. P. Paganini's new Phototopographic Instrument for Reconnaissance Surveys on Scales of 1:50000 *and* 1:100000 *(Model of* 1897).

To overcome the difficulties encountered in the topographic reconnaissance work (1:100000 scale) in Eritrea (East Africa)—due principally to the torrid climate—and in Sardinia (1:50000 scale)—on account of the danger of contracting malarial fevers—L. P. Paganini has devised another surveying-camera, smaller, more simple in form, and easier in manipulation than the type just described.

This instrument (model of 1897) combines rapidity in the field operations with a minimum expenditure of money, and it materially reduces the period during which the operator has to be exposed to the vicissitudes of climate and weather. It is compactly built, essentially light in weight, and preserves the various adjustments, when once made, almost indefinitely, at least for a long time if the instrument is carefully handled.

This instrument, together with all accessories, compass, frame, tripod head, shutter, dark-cloth, etc., may conveniently be packed into a knapsack to be carried by a single packer, the entire outfit weighing only about 15 kilogrammes.

This photogrammeter is composed of the following parts:

First. A photographic camera;

Second. A horizontal graduated circle attached to the vertical axis of rotation, with superimposed alidade bearing verniers and spirit-levels;

Third. An azimuth compass;

Fourth. A tripod with folding legs which may easily be taken apart.

1. The Phototopographic Camera Proper.

The camera of Paganini's latest photogrammeter is rigidly constructed of aluminum. It has been given a prismatic form with an equal-sided trapeze for base. The rear side of the camera-box is formed by a metal frame which supports either the ground glass or the sensitized photographic dry-plate. The plates are 18×24 cm. in size and they are exposed with the longer side horizontally.

Attached to the center of the camera front is a metal collar or tube into which a tube may be screwed having a thread of 1 mm. rise and holding the objective in the outer end. This objective tube is provided with a flat ring soldered near the objective end to the tube in such manner to leave a cylindrical space between the ring and objective tube into which the fixed collar—attached to the front side of the camera—may enter when the objective tube is screwed into the camera collar. The latter has a millimeter graduation on its outer surface extending in the direction of the optical axis. The rear (beveled) edge of the flat ring is divided into ten equal parts, and when the objective is brought nearer to or farther from the image plane—by revolving the lens tube about its axis—the beveled edge of the flat ring will slowly be moved over the millimeter scale. Furthermore (this beveled edge being divided into ten equal parts), the position of this circular scale on the beveled edge with reference to the longitudinal millimeter scale will permit the focal length to be read to tenths of a millimeter for any position of the lens.

The objective of this camera is a Zeiss wide-angle anastigmat with a principal focal length of 182 mm. With a small diaphragm stop it produces a picture of 40 cm. diameter, equivalent to an angular field of 104°. With the diaphragm aperture $f/35$

it covers a plate of 20×26 cm. very well, and as the adopted size of plate is only 18×24 cm. we obtain a very clear and sharp definition over the entire plate even when using a larger diaphragm opening.

The perspectives obtained with this camera command an angular field of 67° horizontally and 53° vertically. With six plates we can, therefore, cover an entire panorama view (of 360°) from which vertical angles of elevation or depression may be deduced up to $\frac{53^\circ}{2}$ ($=26^\circ\ 30'$).

Two adjoining plates have a common vertical margin of 3° 30′ in width. Horizontal angles between points falling within this panoramic zone or belt of 53° angular width may also be deduced from the six plates iconometrically.

This instrument has been carefully constructed with optical axis of the camera perfectly normal to the image plane, and the point of intersection of optical axis with the image plane—the principal point—is photographically transferred to every photographic perspective as the point of intersection of the pictures of two very fine silver wires crossing each other at right angles. These wires are secured, quite close to the image plane, in such manner to be easily removed and replaced by others in case they should accidentally be ruptured.—Directly below the camera-box, attached to its lower side or base, are three Z-shaped metal arms with rectangular bends. One is placed immediately below the objective and the other two in the rear, below the cross-wires. The lower (horizontal) arms of these metal Z bars are equidistant from the camera base, and they are perforated by smooth circular openings which readily receive three stout screw-bolts securely and permanently attached at right angles to the alidade of the horizontal circle. Each one of these bolts has two nuts of which the lower one supports its corresponding Z-bar arm, while the upper nut has been added as a locking device to secure the position of the lower nut together with the corresponding Z-bar arm at any desired height, after

the proper adjustment of the camera's position on the horizontal circle has been made.

2. The Horizontal Graduated Circle.

The horizontal circle of this photogrammeter has a diameter of 14 cm.; it is graduated into half-degrees and reads from 0° to 360°. The vernier reads to single minutes, but 30 seconds may be estimated. The vertical axis of rotation of the instrument projects above the plane of the alidade and the latter is secured in a plane at right angles to the axis of rotation by means of a stout collar covering the latter.

The instrument is supplied with three leveling-screws, clamp- and tangent-screws, spirit-levels, etc., the general arrangement being the same as for any other surveying-theodolite.

The metal tripod head supports a circular spirit-level for an approximate adjustment into position of the vertical axis, the final leveling being accomplished by means of the three leveling-screws, which form the support of the instrument on the tripod head, together with a pair of cross-levels attached to the alidade surface.

The superstructure is secured to the tripod head, precluding an accidental upsetting, by means of a central clamp-screw with spiral spring and a long handle for an easy manipulation between the tripod legs, the same as shown for the other Italian photogrammeters.

3. The Azimuth Compass.

On the upper surface of the camera-box is a cylindrical receptacle of pure aluminum, to receive the magnetic compass which is modeled after the so-called Dixey or Schmalkalder pattern, so well adapted for topographic work. It has the usual prismatic eyepiece and vertical hair-sight, which are permanently fixed in the vertical plane which passes through the optical axis of the camera objective.

4. The Tripod.

The tripod of this photogrammeter is practically the same as has been described for the other Italian phototheodolites, except that the legs are folding and may be carried together with the instrument by one packer.

5. Adjustments and Use of this Instrument.

Before commencing the regular phototopographic survey of a given area with this instrument, certain observations should be made which, however, will serve equally well for all subsequently occupied panorama stations, and certain adjustments should be made or verified which, owing to the stable and solid construction, will also remain in stabiliment for a long time thereafter.

Of course, the operator should, after all the adjustments have once been made, check them from time to time, particularly when it may be supposed, or when it is known, that the apparatus had been subjected to unavoidable shocks or careless handling by packers while in transit over rough roads or trails. With an adjusted instrument and careful handling the final adjustment that will be necessary to be made before occupying the camera station for observing reduces itself to a small matter.

The first step when the phototopographic survey of a given area is to be made consists in a most accurate determination of the constant length of the focal distance, which is preferably done on a bright day in the following manner: The objective is moved back or forth until some far-distant but well-defined points of the terrene appear well outlined and quite sharp in definition on the ground-glass plate under the dark-cloth, using a small magnifying-glass to ascertain the position of the plate (the focal length) giving the best definition. It is advisable to focus in this manner successively upon several well-defined distant points, reading the scale indications for each point focused

upon and entering the records in the field-book. We will thus obtain a definite value for the principal focal length, as indicated by the mean of the recorded scale-readings.

We next determine the diaphragm aperture which is to be used for the entire panorama, selecting the smallest stop that will yet give a uniformly good definition for the entire field controlled by the plate—60° in azimuth and 45° in altitude—having special reference to a good definition of the summits of distant mountains that may be shown on the perspective.

The adopted diaphragm aperture—the instrument in question has a revolvable diaphragm disc with numbered apertures of graduated sizes—at different hours of the day, at different altitudes, and under different illumination ("light-intensity") will only in part control the length of exposure, as the latter also depends in great measure on the rapidity ("sensitometer number") of the plate that may have been selected for use in the survey, and on the so-called rapidity of the lens, together with the color screen, if such is used.

A systematic exposure of a few trial plates under different conditions regarding hour of the day, elevation of station above sea horizon, and illumination—lens, diaphragm aperture, and plate remaining the same—will give valuable data for future reference and for judging the required length of exposure correctly under similar conditions.

One indispensable condition to be fulfilled when proceeding to make the final adjustments of this instrument would be to make a complete turn of the camera about the vertical axis, very much the same as when exposing the plates for a complete panorama. If the instrument is well assembled with all its parts in rigid adjustment, and if the tripod is securely placed in position on firm ground and no disturbing causes interfere, the instrument should, while being thus rotated, maintain its axis (and its image plane) perfectly vertical.

To realize this condition the cross-levels attached to the upper surface of the alidade should be well adjusted. This

may be accomplished by means of the three leveling-screws which transverse the tripod head and form the support of the superstructure, in precisely the same manner as such adjustment would be made with an ordinary surveying-theodolite.

After establishment of the verticality of the axis of rotation there still remains the adjustment into position of the rigid system of the three orthogonal axes, which have their common origin—point of intersection—in the principal point of the perspective. This system of coordinates is composed of:

First. The optical axis of the photographic camera, representing the principal ray of the photographic perspective.

Second. The two axes intersecting each other at right angles—one horizontal and the other vertical—which are visible on the ground glass and which are photographically transferred to the photographic perspective, where they represent the horizon and the principal line respectively.

The rectangular intersection of these two lines (last named) is perfectly obtained by the instrument-maker. Two very fine silver wires are strung quite close to the image plane, where they are held in position by thin metal plates, the required tension being applied by means of pressure-screws. The correct position of these cross-wires with regard to the rear metal frame of the camera-box is assured by four fine incisions made with a dividing-machine into the rear metal surface of the frame against which the ground-glass plate or the sensitized photographic plate rests when they are in position.

The degree of accuracy with which this rigid system of axes is placed into position (and the degree of accuracy in their directions regarding horizontality and verticality) in a great measure controls or determines the attainable accuracy in the iconometric plotting, based upon pictured points referred to that system of lines as coordinates.

The optical axis of the camera, which by construction intersects the perspective plane—the image plane—at right angles in the principal point, should be horizontal, and therefore the

optical axis should intersect the plane containing the two axes of coordinates (the cross-wires) also at right angles. It is furthermore required that the wire representing the horizon line of the perspective be horizontal, or, in other words, the optical axis of the camera and the horizon line of the perspective are to be in the same horizontal plane—that is, in the horizon plane of the camera station.

This condition may easily be fulfilled by using the screws which support the three Z bars as three leveling-screws. The three lower arms of these Z bars are first placed approximately at equal altitudes above the plane of the alidade circle (which previously had been leveled) by means of the supporting nuts, having first loosened the upper counter nuts to permit the Z-bar arms to move freely over the upright screw-bolts. Now observe the image on the ground-glass plate and bisect a distant point with the pictured intersection of the cross-wires. Change the pointings to the distant bisected point to different positions along the line defining the horizon by revolving the camera in azimuth from left to right, or *vice versa*, at the same time raising or lowering the screws which support the rear Z-bar arms of the camera, until a point is found bisected by the intersection of the cross-wires, which, when turning the camera about the axis of rotation, does not leave the horizon wire, rather continues to be bisected by that wire while being moved over it from one extremity to the other, falling neither above nor below that wire, during the full azimuthal swing through the entire length of the ground glass.

If this distant bisected point was not in the horizon plane of the camera-theodolite, the curve which it describes on the ground-glass surface—during the revolution of the camera through an azimuthal field of 60°—will be traceable with the eye, the point while in transit will pass over the vertical wire above or below the point of intersection of the two cross-wires, according to its position in nature, whether below or above the horizon plane of the instrument.

The farther removed from the intersection of the cross-wires the crossing of the pictured distant point over the vertical wire is the greater will be the curvature of its hyperbolic trace on the ground-glass plate and the greater will be the vertical distance between the bisected point and the horizon plane.

From the preceding remarks it will be evident that the Z bars supporting the camera in the rear may be adjusted by simply watching the courses of points of different elevation as they are traced (by the points while in transit) on the ground glass during the azimuthal swing of the camera. If the distant point, having the same elevation as the optical axis of the camera, leaves the horizon wire and passes over the vertical wire above the intersection of both, the supporting Z bars (those under the rear frame) are to be lowered and *vice versa*. The distance between the point of crossing and the point of intersection of the cross-wires gives a measure for the amount of change to be made in the elevation of the rear Z-bar supports.

After a few carefully made trials, the position of the horizon wire will be such that any point bisected at one extremity of the horizon wire will continue to be bisected by that wire during the revolution of the camera through a horizontal field of 60°. When this has been accomplished the counter-screws of the upright screw-bolts are tightened to secure (the Z bars) the camera in this position with reference to the horizontal circle.

This adjustment once made and secured will be maintained undisturbed for a long time and the horizon wire will now coincide with the horizon line of the photographic perspective for all positions of the optical axis, when the camera is rotated about its axis during the exposures of the plates comprising a panorama, provided, of course, the phototheodolite's axis of rotation has remained vertical.

The final adjustments to be made in the field after the phototheodolite has been placed in position at a carefully selected phototopographic station may now be summed up as follows:

First. Adjust the camera's objective to make the principal focal length, previously ascertained and recorded in the field-book, agree with the reading on the "objective scale."

Second. Verify the position of the rotary diaphragm in order to have the particular aperture in position that may be required for the particular brand of plate under the particular conditions of the atmosphere at the place occupied. Also verify the setting of the time-shutter to see that the exposure will be correct for this particular diaphragm aperture, plate, illumination, altitude, and subject, although the latter plays a minor rôle here, as it seldom varies much in phototopography.

Third. Verify the level adjustments and see that the axis of revolution of the instrument is vertical, as the horizontality of the optical axis, the verticality of the image plane and of the "principal" wire, as well as the horizontality of the "horizon" wire, depend thereon.

The preceding descriptions show that much has been done in Italy towards pushing photographic surveying to a high state of perfection, and we are particularly indebted to Paganini for numerous improvements in phototopographic and iconometric instruments, including methods of their use for topographic and hydrographic surveys. Paganini's good results, his experience, and advice have materially aided in the decision in favor of the phototopographic method in a number of surveys, particularly for the survey of the mountains of the Caucasus (and Tiflis) under the direction of Baron von Steinern.

III. Surveying-cameras Combined with Geodetic Instruments. (Phototheodolites, Phototachymeters, Photographic Plane Tables, etc.)

The data obtained in the field with the photographic-surveying cameras considered in the preceding paragraphs had to

be supplemented with instrumental field observations to gain a complete topographic control of the territory traversed by the phototopographic surveying party.

The idea of combining surveying instruments with a camera into a compact and serviceable apparatus originated very early with phototopographic workers. Refined phototheodolites are to this day the favorite photographic-surveying instruments not only in Europe, but they are also widely in use in other countries, particularly when these are dependent on European mechanicians to supply the demand for instruments of precision.

Phototheodolites have been devised to secure great precision in the results obtained with them; refined methods are largely employed in the field observations in the culling of data from the photographic perspectives, and in the computations.

Generally speaking, the best results for topographic purposes are obtained by methods that have been devised with due reference to the fact that phototopography essentially and primarily is a constructive or graphic art, based on graphic or pictorial records, in the form of perspectives, that are to be transposed into orthogonal projections in horizontal plan, instrumental observations being required only to furnish such elements as may be needed to facilitate the graphic transposition of lines of direction and distances, to insure accuracy, and to obtain certain checks or a proper control for the work in its entirety.

It has already been pointed out in the preceding chapters that phototopography is based essentially on the same methods which are followed in topographic plane-table surveys, and the best results may be expected when the surveying-camera is used with the same object in view which the plane-tabler essays to obtain. To increase the degree of precision the plane-tabler will occupy a greater number of stations, and similarly in phototopography any degree of accuracy may be attained by increasing the number of camera stations for any given area.

Photographic surveys have been conducted principally in

regions where other surveying methods are either precluded or where their application would entail great cost and consume too much time and such regions are characterized chiefly by a rugged and broken topography. The necessity, therefore, lies close at hand to devise instruments which will not easily get out of order or drop to pieces when transported over rugged mountain trails; the more simple their structural composition the better adapted they will be for the production of rapid and accurate work.

In Europe phototopography has generally been employed for surveys plotted on large scales, necessitating the occupation of numerous stations, with a resulting slow progress from one locality to another. Then too the instrumental outfit could readily be brought very near, if not actually to the very place, where the work was to be done, by convenient and safe means of transportation. The instruments are very seldom exposed to such primitive and rough methods of transportation over long distances, as generally has been the case on our continent when surveying-cameras have been used.

It is evident that the combination of a camera and a surveying-instrument into a well-united, well-balanced, easily manipulated, and essentially light and withal rigid instrument is not easily accomplished. It is not surprising, therefore, that we meet with a great number of types of phototheodolites and other photogrammeters in which the difficulties in construction have been overcome, more or less successfully, by various devices. In the following we shall describe the principal types of photographing-surveying instruments that are either of historical interest or are in use at this date.

A. L. P. Paganini's Photogrammetric Instrument (Model of 1884).

The Italian photogrammetric apparatus devised by L. P. Paganini, model of 1884, is illustrated in Figs. 111 and 112, Plates LIII and LIV. It is supported by a tripod which may

be dismembered into the tripod head *H* and three "alpenstocks" *A*. The instrument proper may be separated into two parts, the camera-box *C* and the Y supports with eccentrically located telescope *T*.

S', S', S' indicate the 3-foot screws—only two are visible in the illustrations on Plates LIII and LIV—which form parts of the tripod head *H* and which serve to level the theodolite.

S_1, S_2, S_3 represent three leveling-screws which support the camera proper and which serve to adjust the position of the cross-wires affixed to the rear frame of the camera-box. The camera *C* is connected with the upper limb of the theodolite by means of a catch-lever *K* in such manner that the azimuthal revolution of this limb will also rotate the camera horizontally.

L is a spirit-level attached to the telescope *T*, both being supported by an upright or Y support *U* secured at right angles to the horizontal limb of the theodolite and at one side of but close to the camera.

T is an ordinary surveying-telescope (astronomical) and it is provided with the usual cross-hairs (one vertical and the other horizontal), adjustable in the customary manner.

C represents the camera-box. It is made of hardened pasteboard, which is strengthened by a metal skeleton frame or casing *B*.

The camera is supplied with an aplanatic objective ("antiplanat"), made by Steinheil, having a focal length of 244.5 mm.

The aperture in the diaphragm has a diameter of 5 mm.

Regarding the general arrangement of this instrument it may be said that:

First. The optical axis of the photographic lens (objective) is parallel with that of the telescope T and it always is perpendicular to the picture or image plane.

Second. The intersection of the optical axis of the camera and picture plane—the principal point of the photographic perspective—is marked by the point of intersection P, Fig. 113, Plate LV, of two very fine and adjustable platinum wires OO' and ff' securely fastened to the rear frame of the camera-box, very close to the image plane.

When the instrument is leveled and in adjustment one of these fine wires (OO') will be horizontal, while the other (ff') will be vertical, and both will be in a (vertical) plane parallel to the image plane.

The optical axis of this camera may be brought into horizontal plane by rotating the same about the horizontal axis CC, Fig. 111, Plate LIII, and clamping the screw h. In this position the image plane and plane containing the platinum cross-wires OO' and ff' will both be vertical.

The horizontal wire OO' may be adjusted into horizontal plane, after the instrument has been carefully leveled, by finding some easily identified and readily recognized point on the ground-glass plate, which is bisected by this wire OO', and by gently revolving the camera in azimuth. If the wire OO' is in horizontal plane, the observed point will be seen to move over the entire length of the wire while the revolving motion is given the camera. Should the bisected point, however, appear above or below the wire OO' at any time during the azimuthal revolution of the camera, the same will have to be adjusted into horizontal plane by aid of the two front screws S_2 and S_3, Figs. 111 and 112, Plates LIII and LIV.

The camera is provided with a short tangent or slow-motion screw t, by means of which the same may be slightly moved in azimuth, while the telescope T and horizontal limb of the theodolite remain stationary. This arrangement will enable the observer to place the optical axis of the camera parallel to

that of the telescope *T*, provided both had been adjusted in horizontal plane. This correction is made by "pointing" the telescope to some well-defined distant point and clamping the theodolite in this position. The camera is now moved by means of the tangent-screw *t* to the right or left until the same point appears in the intersection *P* of the two camera wires *OO'* and *ff'*.

The prints of the camera cross-wires *OO'* and *ff'* appear on every negative taken with this instrument, and as their plates were exposed while vertical to the optical axis of the camera, the perspectives that are obtained (after the instrument had been adjusted as described) are in vertical plan, each showing the principal point of view *P*, as well as the principal and horizon line *f'f* and *OO'*, intersecting each other in *P* at right angles. The horizon line *OO'* on the picture represents the intersection of the horizon and picture plane. All points on the picture bisected by the horizon line have the same elevation (disregarding the error due to curvature and refraction) as the optical axis of the camera at the station whence the picture was taken.

In place of the fixed platinum wires some photographic-surveying instruments have four sets of teeth (or a series of notches) attached to the rear frame of the camera-box, close to the picture plane (Fig. 114, Plate LV). If prints are used for the map construction instead of the plates, this arrangement is preferable to the fixed wires, as the latter often obscure details and as the prints may be distorted to such a degree that the lines *OO'* and *ff'* may have to be corrected, thus giving two sets of lines across the face of the print. When only the ends of the cross-wires are indicated on the pictures by means of the teeth, the correct positions of the cross-lines may be ascertained or checked experimentally and the lines are then drawn across the face of the picture by very fine lines in red ink.

Great care should be exercised in the proper location of those lines, as they form a rectangular system of coordinates to which every pictured point that is to be mapped must be referred. They

also play an important part in ascertaining the value of the focal length of the picture, which is one of the principal elements required in iconometric plotting.

Fig. 112, Plate LIV, shows the camera in a position to take a picture of terrene so far below the camera horizon that the plate when exposed in vertical plane would not "take it in." The construction of the instrument will permit a depression (or an elevation) of the optical axis of 30° below (or above) the horizon by loosening the clamp-screw and revolving the camera about the secondary axis of rotation. (See paragraph on inclined picture plates.)

Constant Focal Length of the Italian Cameras.—Fig. 115, Plate LV, shows the longitudinal section of a surveying-camera with the diaphragm AB in position between the lens doublets. The aperture of the diaphragm is taken as 5 mm. in diameter. Only such rays of light emanating from a point N in nature will reach the point n on the image plate II that form a cone about the central ray nON as axis, with apex in n and base in O. For the case illustrated in the diagram (Fig. 115, Plate LV), that base will be an ellipse with 5 mm. length for the short axis, while a pencil of light emanating from a point C on or very close to the optical axis of the objective would be intercepted by the plane of the diaphragm AB in a circle of 5 mm. diameter.

The Italian lens is so focused that even for the largest aperture of diaphragm used, all points from 10 meters to infinite distance from the camera-lens O, Fig. 115, Plate LV, will be clearly photographed with a maximum error in definition of 0.06 mm. (for 10 m. distant objects).

If a=distance of object from the point O (10 meters to infinite distance);

f=principal focal length of the camera (240 mm.);

b=focal distance, variable for different lengths of a;

we find from the well-known relation

$$\frac{1}{f}=\frac{1}{a}+\frac{1}{b},$$

$$b = \frac{af}{a-f}.$$

By adopting 240 mm. as value for f, and substituting different values, from 1 meter to 300 meters, for a in the preceding formula, we obtain the following values for b:

a (in m.) =	1	10	20	30	40	50	75	100	200	300	∞
b (in mm.) =	315.8	245.9	242.9	241.9	241.4	241.1	240.7	240.5	240.2	240.02	240.00

The error, therefore, in maintaining the focal distance constant is 6 mm. if the object is 10 meters distant from the nodal point; it is 1 mm. if the object is 50 to 100 meters distant and it is inappreciable if the object is 300 m. or more distant from the nodal point of the camera-lens.

The value $\left(\frac{x}{2}\right)$ of the error (lack of definition or distortion) produced in the photograph for points or objects at different distances (a), when maintaining a constant focal length, may be seen from the following: Assuming again that the image plane II, Fig. 115, Plate LV, be held in a fixed position and 240 mm. distant from the nodal point of the lens, it will be evident that the image plane II (Fig. 115, Plate LV) will intersect some of the light pencils or cones of rays (passing through the aperture O of the diaphragm) in a circle (or in an ellipse) instead of intercepting their apex. We see from an inspection of the foregoing table that this circle of diffused light will increase in size with a decreasing distance (a) of the object to be photographed. The true point would be the center of the circle and the length of its diameter x may be ascertained from the following relation (Fig. 116, Plate LV):

$$x : O = f : a,$$

$$x = \frac{f \cdot O}{a}.$$

Again assuming (Fig. 116, Plate LV)

$f=240$ mm. (principal focal length),
$a=1$ meter to infinite distance, and
O=diameter of aperture in diaphragm $=5$ mm.,

we find the following values for x from the preceding formula:

a (in m.) = 1	10	20	30	40	50	75	100
x (in mm.) = 1.20	0.12	0.06	0.04	0.03	0.025	0.016	0.012
a (in m.) = 200	300	400	500	700	1000	∞	
x (in mm.) = 0.006	0.004	0.003	0.003	0.002	0.001	0.000	

The diameter x of the circle (or ellipse) is evidently quite small, and a constant focal distances may well be maintained for all phototopographical work without producing any appreciable error.

In order to enable the observer to obtain good definition in the pictures of objects not very distant from the camera the Italian apparatus was devised with a movable objective and provided with a metal scale (a, Fig. 111, Plate LIII) extending in the direction of the camera axis, which reads zero (or rather 240 mm.) when the camera has been focused upon objects at infinite distance. The millimeter graduation of this scale, extending in the direction toward the sensitive plate of the camera, enables the observer to measure the focal length directly if the same had been changed at any time from the principal focal distance (=240 mm.). The objective cylinder M, Fig. 111, Plate LIII, may be moved in the direction of the camera axis by revolving it within N, both tubes N and M being connected by means of a screw, the rise of its thread being 1 millimeter.

The circumference of N is divided into ten equal parts, and the position of the metal scale a, passing over this graduation, when the objective tube M is screwed into N, will indicate the tenths (and estimated hundredths) of millimeters which it had been moved beyond the number of millimeters read off on scale a.

The focal length plays a very important rôle in all photo-

topographic work, and it is advisable to verify, at the beginning of operations, the reading of the metal scale, and if the principal focal length has been changed, the difference must be entered into the note-book, so that the proper correction may subsequently be applied.

The distance of the point of view from the perspective plane, the position of the principal line, and the correct position of the horizon line can always be ascertained or rectified by instrumental observations and computations, or graphically (if the picture plane has been exposed in vertical plan or if its deviation from that position be known) as has been indicated, and as will be shown more fully later.

It has been described how the optical axes of the telescope and of the camera are brought into two vertical and parallel planes. Both may be kept in this position and yet be revolved about the vertical axis of the instrument in order to successively expose the plates covering the entire panorama. The horizontal limb of the theodolite is divided into 360° with subdivisions reading to 20′, and by means of two verniers 30″ may be read off. The vertical circle is provided with the same graduation and similar verniers. Thus the means are provided to ascertain the azimuthal positions of the camera axis (the principal ray) for each perspective, or the means of "orientation" are thus provided for. The magnetic azimuth of the principal ray of the perspectives (i.e., direction of optical axis for each exposure) or the horizontal angle which is included between said ray and any other line passing through the station and some known point on the photograph (e.g., trigonometrical point) may readily be ascertained by observation.

All perspectives that are to be used for mapping must be obtained from stations with known geographical positions. Generally trigonometrical points are selected for the camera stations, but if points beyond these have to be occupied to better control the topography, the elements needed (horizontal and vertical angles) to determine their positions with respect to sur-

rounding triangulation points may readily be observed with the theodolite before leaving the detached camera station.

B. L. P. Paganini's new Phototheodolite (Model of 1894).

The following description of *Paganini's new phototheodolite* has been extracted from his "Nuovi Appunti di Fototopagrafia," Roma, 1894.

Paganini's new phototheodolite, model of 1890, differs from the one just described, although the general form and the dimensions of the camera-box, as well as the focal length of the lens, remain about the same as with the older model. The principal change rests in the omission of the eccentric telescope, which has been replaced by the centrally mounted camera, which may, at will of the observer, be converted into a surveying-telescope.

The telescope which we generally find attached to surveying-instruments consists of a tube, slightly conical in shape, having a positive lens (or a system of convergent lenses) at one end, known as the "objective," which produces within the telescope a real and inverted image (the same as the camera-lens) of any object towards which this telescope may be directed. The other smaller end of the telescope-tube has a still smaller tube inserted into it which may be moved in the direction of the axis of the tube. This second tube also contains a system of convergent lenses—it is the so-called "ocular" lens set or "eyepiece" of the telescope—which serve to project an enlargement of the image—formed in the telescope—upon the retina of the observer's eye.

In the image plane of the objective the so-called diaphragm is placed; it is a ring-shaped metal disc to one side of which a pair of cross-hairs is attached in such a way that the hairs (spider webs or lines cut into the surface of a thin plano-parallel glass plate) will coincide with the image plane. One hair is horizontal and the other vertical, their point of intersection falling in the optical axis of the telescope.

A suitable eyepiece had only to be combined with the objective of the older camera model to convert the camera into a

telescope. The eyepiece of the camera telescope, camera model of 1890, consists of a positive lens set, known in optics as Ramsden's ocular lens.

The inner wall surfaces of the camera-box should be well blackened to avoid side reflections and a consequent dimness in the appearance of the cross-wires of the camera telescope.

The camera proper consists of two parts, a truncated pyramid *A*, Figs 117–119, Plates LVI–LVIII, and a cylindrical attachment *B* containing the tube *t*. A second tube, placed within the tube *t*, may be moved in the direction of the optical axis by means of a screw the threads of which have a rise of 1 millimeter. By rotating this inner tube the lens may be brought nearer to or farther from the image plane, the lens remaining parallel to the image plane at any position that may be thus given it.

A scale *a*, Fig. 117, Plate LVI, graduated to millimeters, is permanently attached to the tube *t* and it lies very close to the ring *n*, the circumference of which is divided into ten equal parts (this graduated ring *n* is soldered upon the cylinder *u* encasing the camera-lens). This scale *a* (extending in a direction parallel to the optical axis of the lens) has a mark coinciding with the index rim of the ring *n*, thus indicating the focal length of the camera-lens when focused upon objects at infinite distance. The millimeter graduation of the scale *a*, extending from the zero mark towards the ground-glass, serves to ascertain the focal lengths for objects nearer the camera. The graduation on the ring *n* serves to read one tenth of one revolution of the tube *u*, which is equal to an axial motion of the lens of 0.1 mm., hence the focal length for any object focused upon may be read to single millimeters on the scale *a* and to tenths of a millimeter on the graduated ring *n*.

The construction of this phototheodolite is such that the optical axis of the camera-lens is always at right angles to the picture plane (the ground-glass surface or sensitive film of the photographic plate). The intersection of the optical axis and the picture plane (the so-called principal point of the perspective) is

marked by the intersection P, Fig 113, Plate LV, of two very fine platinum wires, OO' and ff', one horizontal and the other vertical. They are stretched across the back of the camera-box as close as possible to the picture plane. The buttons b, Figs. 117 and 118, Plates LVI and LVII, serve to impart tension to the wires. The horizontal line OO' corresponds to the horizon line and the vertical line ff' corresponds to the principal line of the perspective represented by the image on the ground-glass surface.

Fig. 119, Plate LVIII, shows the rear view of this instrument, the ground-glass or focusing plate having been replaced by an opaque plate stiffened by a metal frame, which supports the Ramsden eyepiece in the center in such manner that its optical axis coincides with that of the camera-lens. The cross-wires OO' and ff', at the rear of the camera-box, serve also for the astronomical telescope, into which the camera may be converted by attaching the opaque plate with central eyepiece as shown in Fig. 119, Plate LVIII.

The fitting of the eyepiece allows for axial motion to adjust its position with reference to the cross-wires to avoid parallax. The opaque plate supporting the eyepiece is composed of a thick cardboard impregnated with chemicals to harden its fibers and to render it impervious to moisture. The camera-box is made of the same material and both are strengthened by a frame and ribs of metal, as indicated in Figs. 117 and 118, Plates LVI and LVII. The cylindrical tube B is inclosed by a metal collar C which is held in position within the metal ring ll' by four screws R, R', S, S'. The ring ll' is connected with the frame gg' by means of two arms lg and $l'g'$, all being cast in one piece. The pivots q attached to the frame gg' serve as horizontal axis of rotation for the camera.

This instrument is provided with a vertical circle, horizontal circle, verniers, reading-microscopes, levels, clamps, and tangent-screws, forming a complete transit with centrally located camera telescope.

A cross-section of this instrument is illustrated in Fig. 120,

Plate LIX. The scale *a*, already described, is here placed on top of the tube *u*, to better illustrate its use.

yy = uprights forming the supports of the horizontal axis of rotation for the camera telescope;

h = upper horizontal limb, or alidade, supplied with two verniers;

H = lower limb, or horizontal circle, bearing the graduation;

TT = tripod head, supporting the instrument by means of three leveling-screws (*W*);

a = casing for conical center;

q' = central clamp-screw entering a ball which is supported by the hemispherical socket ω of the lower part of *a*. *q'* secures instrument to tripod-head and it guards against an accidental falling off of the instrument.

The horizontal circle, having a diameter of 17 cm., is graduated into 20 minutes and suitable verniers are supplied to read horizontal angles to 30 seconds.

The vertical circle, with a diameter of 10.5 cm., is graduated into 30 minutes and its verniers read to single minutes.

The photographic plates are 18×24 cm., which is the same size as for the older instrument, model 1884.

The objective lens, at first selected, was an aplanat of Steinheil, and it had a focal length of 237.7 mm. More recently, however, the Italian phototheodolites have been supplied with anastigmatic lenses of Zeiss.

The column *E*, Figs. 117–119, Plates LVI and LVIII, forming a prolongation of the lower arm *l'g'*, is held in place by two counter screws *m* and *m'*, which serve to hold the horizontal axis of rotation of the camera in a fixed position, preventing accidental changes that might otherwise take place during the execution of a set of panorama pictures.

By unscrewing the nuts *d'*, Fig. 120, Plate LIX, the tripod legs may be removed and they may then serve as "alpenstocks" during the transportation of the instrument from station to station. The "camera telescope" may be lifted out of the Y's and packed separately, the lower part of the instrument—the sub-

structure—is packed in another carrying-case, while the plate-holders and plates are transported in a third case.

C. L. P. Paganini's Photographic Azimuth Compass (Photographic "Azimutale").

During the last years of Paganini's service as an officer in the Royal Navy of Italy, while in command of the cruiser "Tripolis," he was engaged upon work connected with making descriptions of the coast ("coast-pilot work"), and with hydrographic surveys for the construction of harbor and sailing charts. This work, undertaken for the production of better navigation guides, entailed a minute study of the approaches from the sea and a thorough reconnaissance of the coastal belt of topography.

Landmarks available and useful for sailing-guides were to be accurately determined and plotted upon the hydrographic charts. Paganini was particularly instructed to obtain pictorial views of certain coast regions, showing the appearance of the coast when viewed from certain points off shore and giving the magnetic bearings to certain reference points shown on the views from the points marked on the charts whence the views were obtained. The point of view was determined either by means of the three-point problem or it was indicated by means of the estimated distance from some well-defined landmark (lighthouse or other prominent object) giving also the magnetic bearing.

The perspectives used to illustrate parts of the coasts, in order to facilitate the identification of the "landfall" by mariners when approaching the coast from the open sea, were published either on the charts or in so-called coast-pilot books. Formerly they were obtained by drawing a free-hand perspective from the deck of a vessel, including all prominent features and sailors' landmarks, particularly lighthouses, lone trees, prominent bluffs, and other characteristic features or marks.

Such perspectives (Beautemps-Beaupré and Porro had a remarkable skill in producting accurate perspectives of such

terrene views by offhand sketching) could not be made with mathematical precision, and very few draughtsmen have the gift to draw these perspectives under such conditions rapidly and of uniform scale. Their subsequent reduction to paper, under application of empirical and often arbitrary rules, based on sextant angles, magnetic bearings, and the mentioned defects in the sketches, had but a doubtful value, particularly if the vessel, during the time period which was consumed while these various observations were made, had gradually changed its position, due to winds and sea currents.

Paganini, fully appreciating these difficulties, soon recognized the value of photography for obtaining such perspectives more readily and far more accurately, if a suitable photographic instrument could be constructed to be used on shipboard, the use of an ordinary camera, of course, being precluded.

For several years Paganini made studies and experiments with the above object in view, particularly since the instantaneous photographic process had been perfected, and the photographic azimuth compass ("azimutale fotografico") is the direct result of his labors in this direction. It was devised to subserve the demands touched upon in the preceding paragraphs, and the instrument, described in Paganini's "De nuovi Appunti," has been made by Galileo in Florence.

This instrument may serve to locate with accuracy lighthouses, buoys, and rocks awash, to obtain topo- and hydrographic views of the coast (for coast, harbor, and wharf surveys) for explorations and scientific expeditions, for the survey of unexplored coastal belts, for naval reconnaissance, for picturing naval displays and engagements, etc. It is furthermore adapted to determine the geographical latitude of a vessel's position by photographing the altitude of the sun above the sea horizon, including its magnetic bearing at the moment of the plate's exposure. From a negative showing the image of both the sun and the sea horizon the declination and the azimuth (magnetic) of the sun may be deduced, and the time being known when the plate was exposed,

the geographic position of the camera may be deduced from the plate.

Paganini's photographic azimuth compass is shown, in a general way, in Figs. 130 to 133, Plates LXV to LXVIII. The photographic plates are exposed in this instrument with the long sides (24 cm.) horizontal and the short sides (18 cm.) vertical.

The objective is very similar in arrangement to that described for the Italian phototheodolite, having a graduated scale to enable the observer to obtain the focal length directly. The two cross-wires, with their point of intersection in the optical axis of the lens, are secured in the image plane, the same as with the phototheodolite.

The camera-box *C* is supported by two upright pieces *S*, shaped like an inverted U; at the top they are united by a horizontal plate *Z*, extending from the two camera sides around to the front of the camera, forming a horizontal connection in the shape of a horse-shoe. Three projections *d*, one at the front and two at the sides of the camera, serve to support the camera-box upon the horizontal frame *Z* by means of three pairs of counter screws *v*. In the sectional view of the instrument, Fig. 133, Plate LXVIII, *r* indicates the vertical axis of rotation, *gg* the horizontal circle, *B* the azimuth or ship's compass, *VV* leveling-screws (supporting the horizontal circle on the heavy plate *TT*), *Q* a heavy weight (to lower the center of gravity of the apparatus and to increase the stability of the same when used on the deck of a rolling vessel), *m* is the handle of central screw (clamp) which passes through *Q* and enters a spherical nut attached below the horizontal circle, to allow for lateral swing when leveling the camera with the foot screws *V*.

When this instrument is used on land the gimbal support is replaced by a special surveying-tripod, the instrument resting on the latter by means of the three leveling-screws *V*. The illustrations show the instrument with the gimbal support the way it is used on shipboard. The three leveling-screws *V* rest upon a plate *TT* which is connected with the stout ring *A* by gimbals, the ring *A* in turn being supported by four stout legs. The

weight Q is sufficiently heavy to assure the vertical axis of rotation r, Fig. 133, Plate LXVIII, to remain always vertical. This apparatus is best adjusted and tested on shore, in order to adjust the horizontal thread OO' by means of the sea horizon.

Below the under side of the camera-box (the latter is inclined about 30°) another smaller camera c is placed, close to the middle of the rear end, having a prism attachment by means of which a section of the compass graduation is reflected upon the lower edge of the photographic plate, the pictured graduation extending to both sides of the pictured principal line ff', as indicated in Fig. 134, Plate LXVIII. The shutters of both cameras, C and c, are operated simultaneously by pressing the rubber bulb b, Fig. 132, Plate LXVII. The rubber tube attached to the bulb is forked, a separate branch leading to each pneumatic shutter, as indicated in Fig. 132. The optical axes of the cameras are at right angles to each other and both are in the vertical plane containing the principal line ff'.

The diameter of the dial compass passing through the zero mark of the graduation is identical with the magnetic meridian, and the compass-reading, designated by the graduation mark that is bisected by the prolonged vertical thread ff' below the picture, represents the magnetic azimuth of the optical axis of the instrument at the moment of the exposure, or it will indicate the angle of orientation for the picture. The vertical frame E, Figs. 132 and 133, Plates LXVII and LXVIII, has a set of cross-wires with their point of intersection in the vertical plane which passes through the optical axis of the camera. A peep-hole O, also situated in the vertical plane passing through the optical axis of the camera, is affixed to the upper horizontal limb, and with the cross-wires in E, it will enable the observer to direct the camera to any point that is to be bisected by the principal line when a plate is exposed.

Also this instrument is provided with a Zeiss anastigmat lens of 250 mm. focal length. Eastmann's films or plates are used (18×24 cm.) and the horizon may be covered by eight plates,

allowing a liberal marginal overlap, each plate covering an angle of about 50° horizontally.

D. Photogrammetric Theodolite of Prof. S. Finsterwalder.

This phototheodolite, devised by Prof. S. Finsterwalder after many years of practical work and experience, gained in his alpine surveys and studies of glacial motion, has been constructed by Max Ott (A. Ott), Kempten, Bavaria. In the pursuance of this work Prof. Finsterwalder early recognized the desirability of a surveying-camera of compact build, rigidly constructed in all its parts and yet having a minimum of weight. To avoid the transportation of a separate transit or theodolite for the trigonometric location of the selected camera stations, he provided the surveying-camera with means for observing horizontal and vertical angles.

This phototheodolite is represented in Fig. 135, Pate LXIX, and the total weight of the outfit, 10 kgr., is distributed as follows: The instrument itself weighs 2.7 kgr., its carrying case 2.4 kgr., the tripod 1.7 kgr., one dozen leather receptacles, including twelve photographic plates 2.5 kgr., and the packing-case for the latter 0.7 kgr.

Prof. Finsterwalder has used both an anastigmat lens of Zeiss and a double anastigmat of Goerz, with a focal length of 150 mm. With this focus the lens will photograph perspectively correct a plate of 160×200 mm. The plates used are 120×160 mm., giving an effective horizontal field of 53°, enabling the observer to cover the entire panorama with seven plates.

For the central or normal position of the objective this camera commands an effective vertical field of +20° and −20°, or 40° in all. Twenty degrees above or below the horizon of the camera station would often be insufficient, particularly when working in mountainous terrene. It was deemed advisable, therefore, to mount the objective on a slide, permitting considerable change in the vertical sense. Owing to this device objects subtending

angles of depression up to 35° (together with a vertical angle of elevation of 5°) may still be photographed on the vertical plate.

In extreme cases, when it should become desirable to photograph objects subtending angles of +35° and −35° (or 70° in all), Prof. Finsterwalder recommends the successive exposure of two plates, one with the maximum elevation and the other with the maximum depression of the lens. Inclined plate-pictures are thus not only avoided but the effective plate surface is utilized to the fullest extent and the weight of the glass to be carried is reduced to its minimum.

In order to obtain uniformly accurate and trustworthy results with the relatively short focal length, maintaining a constant distance between the lens and the sensitized surface of the plates, the latter are not placed into plate-holders of the usual pattern (where the variable thickness of the glass plates would affect the so-called "constant" focal length), but they are pressed against a metal frame instead, which frame forms the back of the camera-box, an arrangement very similar to that of Capt. E. Deville's camera. To insert the plate into the camera use has been made of Dr. Neuhauss's leather plate-holders, formed like a sack, *B*, Fig. 135, Plate LXIX. The inner edges of the metal frame are graduated in order to locate the principal and horizon lines upon the negatives.

These leather sacks have metal slot devices facilitating the transfer of the plates from the sacks to the camera and *vice versa*. By hooking the mouth of the sack to the upper edge of the rear camera side and opening the slot while holding the bag in a vertical position, the plate is allowed to slip from the sack into the carrier. Springs attached to the rear of the camera-box serve to check the sliding plate and prevent a too sudden drop of the same into the metal carrier where the plate is to be exposed. These springs also press the plate into perfect contact with the metal frame at the back of the camera-box when once in position.

By withdrawing the upper curved handle (Fig. 135, Plate

LXIX) at the back of the camera the tension of the springs may be reduced (or their action may be released entirely), when the plate will glide into position for exposure. After exposure the lower slide is withdrawn and the tension of the springs is again reduced, when the plate will slip into the empty sack *B*, which had been hooked to the lower edge of the rear camera side as shown in Fig. 135, Plate LXIX.

The eccentricity of the center of gravity, by applying the weight of the sack, including plate, to one side of the camera, does not affect the general adjustments of the instrument sufficiently to throw the photographic plate out of the vertical plane when the exposure is made.

The camera is accurately balanced when no sack is attached, in which form it is used to measure the angles that may be required for locating the camera station, both in the geographical and vertical sense, with reference to the trigonometric signals in the vicinity.

In order to use this instrument as a transit the back of the camera is supplied with an eyepiece *E*, Fig. 135, Plate LXIX, of a magnifying power of from 7 to 8, forming a centrally mounted telescope with the camera objective *O*. The eyepiece is supplied with a cap or shutter to exclude the light when the instrument is used for photographing. A diaphragm with the usual cross-hairs is also attached to the eyepiece.

The camera-lens (or the objective of the camera telescope) being movable in the vertical sense within a range of 100 mm., all objects falling within a vertical range of $\pm 17°$ may be bisected with the telescope. The definition of points to be bisected, when above or below the camera horizon, would become very poor if the eyepiece *E* were rigidly fixed in a horizontal position by means of the arms *NN*, Fig. 135, Plate LXIX. However, it may be revolved about a horizontal axis in such way that it will always be directed toward the center of the camera-lens.

With the double anastigmat of Goerz, which produces a perfectly flat picture, with neither spherical, chromatic, nor astig-

matic distortion, a change in the focus of the eyepiece will rarely be necessary.

Horizontal angles may be observed directly by means of a horizontal circle *H* of 120 mm. diameter, which is provided with two verniers reading to single minutes. Experimental tests made with this instrument have shown that horizontal angles between points of considerable difference in altitude may be observed within a limit of error of 0.4′. This instrument, therefore, gives results sufficiently accurate to locate the camera stations trigonometrically with reference to surrounding fixed points of known positions, provided they are not too far distant to be defined with this low-power camera telescope.

Vertical angles, however, cannot be measured directly; still, by means of the scale and vernier attached to the lens slide or front board of the camera, changes of the objective from its central or normal position—values directly proportional to the trigonometric tangents of the vertical angles—may be read to 0.05 mm. The slide motion of the front board is accomplished by means of a rack and pinion, and experience has proven that vertical angles may be observed with this device within a limit of of error (converted into arc.measure) of 1′.

The three rods designated by *h* in Fig. 135, Plate PXIX, are 100 mm. long and they serve to elevate the instrument support, together with the three leveling-screws *S*, sufficiently high above the tripod legs to allow full play for the leather plate-holders *B*, when they are placed in position to receive the exposed plate. The tripod legs may be folded to half their lengths. No ground glass being provided, a special finder has been devised correctly showing the field controlled by the plate (in both the vertical and horizontal sense) for any position of the camera-lens. (Zeitschrift für Instrumentenkunde, Oct., 1895.)

E. Phototheodolite for Precise Work by O. Ney.

In the construction of this instrument, Figs. 136 and 137, Plates LXX and LXXI, it has been sought to fulfill the following requirements:

First. The camera should be dimensioned for the exposure of plates sufficiently large to produce clearly defined perspectives.

Second. The general disposition of weight and mass should be symmetrical. Both camera and telescope are to be mounted centrally.

Third. The total weight of the instrument is to be reduced to the minimum consistent with rigidity and sufficient strength to assure stability and permanency of its adjustments when used in the field. The integral parts are to be formed to permit a free and easy manipulation of the instrument.

Ney's instrument is composed of two distinct parts—the camera proper and the transit theodolite—which may be used successively and independently one of the other, but always upon the same tripod. The interchange between the two is readily accomplished with accuracy and expediency.

The principal advantages attached to this disposition of the component parts of Ney's phototheodolite may be cited as follows:

First. The symmetrical and central mounting of the camera and transit telescope will insure permanency in the adjustments with consequent accuracy in the results.

Second. By using the same tripod and horizontal circle *T*, Figs. 136 and 137, Plates LXX and LXXI, for both camera and transit their individual weight has been reduced to a minimum.

Third. A possible disturbance of the adjustments of the instrument support *D* and tripod may be guarded against by having the plate inserted and the slide withdrawn before placing the camera-box in position on the upper alidade limb *A*, Figs. 136 and 137, Plates LXX and LXXI.

Accuracy and ease in the manipulation of this instrument have been assured by supplying all leveling- and clamp-screws with spherical ends which rest upon suitable plates in such a manner that a free play of motion will take place. These spherical terminations of the screws were originally devised by Reichel.

Fig. 136, Plate LXX, illustrates the phototopographic camera mounted for use. Fig. 137, Plate LXXI, represents the transit with a striding compass *B*.

D is the very rigid, yet essentially light, instrument support. The three arms supported by leveling screws are cast in one piece with the bearing for the conical pivot, which in turn is securely attached to the alidade *T*. The instrument support *D*, horizontal limb *T*, upper alidade limb *A*, together with the skeleton tripod, are used in common for both transit and camera.

A large circular level *R* is permanently secured to the center of the upper alidade limb *A*.

Three hardened plates are inserted into the upper surface of *A* at *S*. One has a plane surface, the second has a conical cavity, and the third is provided with a V-shaped slot or groove; they receive the spherical ends of the three screws which support the transit and the camera.

The horizon lines of both instruments may be adjusted and brought into the same horizontal plane by means of these sets of three screws each, which are attached to the base of both camera and transit.

Either instrument may be securely bound to the common support *A* by turning the horseshoe-shaped clasps *C*, hinged to *A*, over the ends of the three screws and giving the levers *E* a quarter-turn.

The transit telescope is arranged for stadia-reading (after Porro's method), having 100 as the common multiplier. The telescope-level is graduated to 20″.

The compass graduation reads to 30′ and the horizontal circle reads either to 10″ or 20″, according to the size of the instrument.

The larger class instrument has plates 18×24 cm. and the small-sized camera has plates 13×18 cm.

To avoid changes in the dimensions of the camera-box due to hygroscopical influences of the atmosphere it is constructed entirely of aluminum. The plate-holders and the movable carrier are made of mahogany impregnated with paraffine to render the wood impervious against moisture.

To avoid any possible change in the constant focal length, due to any uneven thickness of the plate-holders or of the photographic glass plates, the carrier may be moved forward in the direction of the camera axis by means of the levers H, Fig. 136, Plate LXX, until the sensitized-film surface is brought into direct contact with a metal frame securely fastened to the walls of the camera. This frame has a centimeter graduation filed into its inner edges, and the distance of the rear surface of the frame from the nodal point of the camera-lens constitutes the constant focal length of the camera.

The centimeter graduation on the inner edges of the metal frame, reproduced on the margins of the negatives, serves a double purpose. By its means the principal and the horizon line may be drawn on the face of each negative, and it also serves to ascertain whether the sensitized films, or the paper prints, have undergone any change in dimension during the process of development. If distortion has taken place the amount of correction to be applied to the print may readily be found.

The camera is provided with a pair of cross-levels to enable the observer to detect any change in its adjustment before exposing a plate. These levels have a graduation corresponding to $20''$ of arc.

When the instrument is in perfect adjustment, the picture plane will be vertical and the principal ray will be in the same horizontal plane as the optical axis of the horizontal telescope if the camera were replaced by the transit (without disturbing the position of the tripod and instrument support).

When this camera theodolite is adjusted the vernier M, Fig. 136,

Plate LXX, will read zero for the normal position of the lens. The objective may, however, be elevated or depressed by 35 mm., and any change from its normal position may be read correctly within 0.1 mm. on the scale and vernier *M*.

The pneumatic camera-shutter is arranged for either time or instantaneous exposures; a special device guards against the possibility of exposing a plate before it is brought into perfect contact with the graduated metal frame. Neither can the plate-holder be withdrawn from the camera before the slide has been replaced nor as long as the plate is in contact with the graduated frame. (Zeitschrift für Instrumentenkunde, 1895, p. 55.)

F. Phototheodolite of Dr. C. Koppe.

Dr. Koppe, Professor at the Technical High School in Brunswick, Germany, is an ardent advocate of photogrammetry and he has done much toward popularizing photographic surveying in Germany.

This phototheodolite, Fig. 138, Plate LXXII, has a centrally mounted camera *K* with the transit telescope *T* on one side and the vertical circle *C* on the other side.

The horizontal axis has been widened between the wyes to form a conical ring *R* into which the camera *K* may be inserted. Four stout springs *f* press the camera securely against the ring surface, forming the collar of the conical ring. After insertion into the ring the camera is revolved, within the former, about its axis until the end of the screw *b* abuts against the stop *d*, when the principal line of the negative should be in vertical plane (the horizon line horizontal).

The camera axis is parallel with the optical axis of the telescope *T*, both axes being in the same horizontal plane when they are level. This parallelism between the two axes is permanent.

The instrument will be in perfect equilibrium with the camera either attached or removed.

The horizontal axis of revolution may be adjusted by means of the striding level *L*, which, when required, may be replaced by a compass very similar to that shown in Fig. 137, Plate LXXI.

Since the telescope (and camera) may be reversed in the wyes the error of collimation and any index error of the vertical circle may readily be found or eliminated.

Neither slides nor plate-holders are provided with this instrument, the plates being inserted directly into the carrier of the camera. This may be done in the field by aid of the packing-case, Fig. 139, Plate LXXII, specially devised to serve as a dark-chamber.

The case proper is made of wood with double doors, each door having a circular opening *A*, Fig. 139, Plate LXXII, filled in with a flexible light- and water-tight material, forming sleeves, in such a way that the hands of the operator may be thrust through an elastic opening in the center of the apron. The fabric closes tightly around the wrists, leaving the interior of the case in perfect darkness and permitting free play of the hands in the interior *L* for manipulating the camera and plates within the case.

The wooden box is incased in a tight-fitting sole-leather covering having two flaps *S* to protect the openings *A* against the admission of dust when the packing-case is transported on the back of the instrument-bearer.

The entire instrument, except tripod, may be stowed away in the case for transportation and safe-keeping. The packing-box also contains two receptacles K_1 and K_2; one contains the unexposed plates and the other receives those that have been exposed during the day's work.

When an exposed plate is to be exchanged, the camera *C*, Fig. 139, Plate LXXII, is placed into the packing-case, and doors, as well as the leather main flap, are securely fastened, the hands are inserted into the sleeves *A*, and the exposed plate *P* is removed from the camera and placed into its receptacle K_1, closing the door *T*. A new plate *g*, taken from the box K_2, is placed into

the camera and its back securely closed, when it will be ready for another exposure.

The constant focal length of this camera is represented by the distance between the second nodal point of the lens and the rear surface of a graduated metal frame permanently secured to the walls of the camera. The inner edges of this metal diaphragm, or frame, bear a centimeter graduation; the middle graduation marks of the two horizontal sides locate the principal line, while the middle graduation marks of the vertical sides represent the termini, on the photographic perspectives, of the horizon line.

The focal length, once determined, remains the same for all plates. This instrument has been manufactured by F. Randhagen in Hannover, Germany.

The Topographic Bureau of Switzerland has used a phototheodolite constructed after the model of Dr. Koppe's instrument. The experience in Switzerland, however, seems to have decided the Bureau of Topography not to replace the plane table by the phototheodolite for general topographic surveys executed by that bureau.

Dr. C. Koppe's new Instrument and Method for Observing Horizontal and Vertical Angles directly on the Photographic Negative.

We have seen, on page 125, that the iconometric plotting of vertical and horizontal changes in the terrene were based upon direct measurements of the coordinates of pictured points. Dr. Koppe, in his recently published pamphlet on photogrammetry, with particular reference to cloud photography, has given a new method having many advantages for particular kinds of work.

He inserts the negative into the camera in the exact position previously occupied by the plate during exposure and illuminates the same from the rear sufficiently to bring out all the details of the negative. With a theodolite telescope directed through the camera-lens he now observes the vertical and horizontal angles by

bisecting the particular points on the negative in the same manner as the surveyor uses a transit for observing in the field.

Light-rays reaching the camera-lens from a distant point in parallel directions are concentrated and directed to one particular point on the photographic plate—the image point. With Dr. Koppe's device the same phenomenon takes place only in inverse order as the light-rays now emanate from the illuminated negative. Light-rays coming from any point of the negative are refracted by the camera-lens whence they enter the telescope of the theodolite in parallel directions. If the telescope had been focused for infinite distance the pictured point observed upon will appear sharply bisected by the cross-webs in the telescope, and if the camera is securely fixed in position and the telescope is now changed to bisect another pictured point, the angle included between the directions to the two pictured points successively bisected will be identical with the angle included between the lines of direction drawn from the first nodal point of the lens at the original camera station in the field to the corresponding two points in nature. We can, therefore, obtain the values for the vertical and horizontal angles by reading the corresponding verniers of the theodolite in both positions of the telescope when bisecting the pictured points.

In the practical application of this method two cases are considered. The camera is either stationary and the observing telescope adjustable in position, or the telescope is stationary and the camera is adjustable. Dr. Koppe has experimented with both types of instruments.

If we insert the negative in the camera, giving it the same position which the plate had during exposure, and if we level the instrument, giving it likewise the same position which it had when the plate was exposed in vertical plane, and finally, if we adjust the observing telescope of the transit to bring its optical axis in line with the horizontal axis of the camera, we can observe horizontal and vertical angles by bisecting the pictured points and noting the vernier readings.

The main difficulty in the practical solution of this problem

was the necessity of having to give the observing telescope a decidedly eccentric position to enable the observer to bisect pictured points at any place of the illuminated negative. The construction of this instrument, therefore, is more cumbersome than the ordinary theodolite or transit with centrally mounted telescope.

Dr. Koppe declares the degree of accuracy attainable in the application of this method to be the same as when the corresponding angles were measured in the field with an instrument of equal size and power. This assertion is based on practical tests and experimental observations made by Dr. Koppe in connection with the preliminary survey for the location of the railroad over the Jungfrau in the Alps.

The principal advantages of this method, compared with angular measurements made directly in the field, may be found in the reduction of the field-work, in the possibility of measuring angles between objects in motion (using instantaneous plates for this purpose), in locating points of an evanescent character, like prominent features of distant mountains which may be liable to sudden disappearance under freshly fallen snow, or which may be visible only for short intervals, due to the frequent and sudden formation of "cloud-caps" or "hoods," etc.

An advantage of Dr. Koppe's method against the general method of measuring the coordinates of pictured points rests in the fact that correct values for the horizontal and vertical angles may be obtained from negatives that are not geometrically true perspectives, owing to distortion produced by imperfect lenses or lens combinations, as the points of the illuminated negatives will emanate light-rays from the first nodal point of the objective in directions identical with those in which they originally arrived there when the plate was exposed. The instrument used by Dr. Koppe in his experimental tests was manufactured by Oskar Günther, in Braunschweig, after plans and specifications furnished by Dr. Koppe. It is illustrated in Figs. 140–142, Plates LXXIII and LXXIV.

The phototheodolite is essentially the same as has been described with a horizontal circle of 14.7 cm. diameter and vertical circle of 12 cm. Aperture of the eccentric telescope is 27 mm., with a focal length of 20 cm. and a Ramsden eyepiece magnifying twenty times. The verniers read to single minutes, admitting 15 seconds to be estimated.

The telescope *r*, Fig. 140, Plate LXXIII, used for angulation, in both the vertical and horizontal sense, upon pictured points has an aperture of 18 mm., a focal length of 8 cm., and its Ramsden eyepiece magnifies five times.

The focal length of the camera objective (double anastigmat of Goerz, series III, No. 1) is 144.9 mm.

Fig. 140, Plate LXXIII, shows the phototheodolite combined with the telescope *r* ready for angulation upon the pictured points of the illuminated negative in camera *Q*.

Fig. 141, Plate LXXIV, represents the various attachments required to convert the phototheodolite, as used in the field, into the form shown in Fig. 140, Plate LXXIII, as used for the angulation in the office. These attachments, of course, need not to be taken into the field.

For the use in office glass positives are preferably made by contact printing from the negatives, as it facilitates the identification of points for the "angulation on pictured points" if these have the same appearance regarding light and shadow as the natural objects which they represent.

To identify corresponding points on two or more positives the plates are placed side by side on a frame with a reflector below them. Points selected for angulation are marked by fine "pricks" made with a needle. Points of reference that have been observed in the field are marked with red ink, giving identical points the same designation, and points to be determined by angulation in the office are marked with blue ink. A check for the correct identification of these points may be obtained in the usual manner by determining their elevations from two or more plates, using, of course, in this case the vertical angles obtained by angulation upon

the pictured points with the telescope *r*, Fig. 140, Plate LXXIII, in the office.

The "spring frame" *P*, Fig. 141, Plate LXXIV, serves to give the various positive plates the positions in the camera corresponding with the positions of the original plates during exposure. This is readily accomplished by viewing the plate through the objective of the camera and adjusting the plate, held against the graduated frame at the back of the camera by means of the spring frame *P*, in such a way that the pictured graduation marks coincide with their corresponding marks on the graduated frame which is permanently fixed in the image plane of the camera.

From the phototheodolites as used in the field we now remove the eccentric telescope, including its vertical circle and circular camera support, from the wyes and replace these with the telescope *r* and vertical circle *B* (Figs. 140 and 141, Plates LXXIII and LXXIV). The secondary camera support *T–t*, Fig. 141, Plate LXXIV, is then secured to the theodolite by means of the clamp-screws *SS*, in the manner shown in Fig. 140, Plate LXXIII, and the camera *Q*, with positive plate in adjusted position, is inserted into the circular camera support *K* (Figs. 140 and 141, Plates LXXIII and LXXIV) and adjusted in position so that the first nodal point coincides with the point of intersection of the horizontal and vertical axes of rotation of the telescope *r*.

The positive plate, if well illuminated by diffused light, will now emanate rays from the marked points in the same direction, beyond the objective of the camera, as the incident rays originally emanating from the corresponding points in nature at the time of the plate's exposure.

We may now proceed to measure the horizontal and vertical angles of the marked points of the plate with the telescope *r*, provided the camera has the same inclination which it had when the original plate was exposed. This inclination may be established by clamping the telescope *r* in position when the verniers of the adjusted vertical circle *B*, Fig. 140, Plate LXXIII, read

the same as the recorded mean value for the inclination of the camera in the field for the particular plate under observation, and tipping the camera, first roughly by means of the support *t*, Figs. 140 and 141, Plates LXXIII and LXXIV, then with the slow-motion screw *h*, Fig. 140, Plate LXXIII, and Fig. 141, Plate LXXIV, until the principal point of the photographic perspective is bisected by the cross-webs of the clamped telescope *r*, which is then released for the angulation of the marked points on the positive plate.

Excepting the angulation upon the triangulation and reference points in the field, the vertical and horizontal angles to any number of pictured points may be observed in the office by this ingenious device, by means of which the greater part of the field-work, when using tachymetric methods, may be transferred to the office, making such detailed observations independent of the length of the field season and of the vicissitudes of climate and weather.

The computations are the same whether such observations are made in the field or in the office, both methods giving practically the same results with instruments of this class.

With Dr. Koppe's instrument the angular values were obtained in both cases within a maximum error of one minute if the bisected points were not farther away than 3000 m.

H. Phototheodolite Devised by V. Pollack; Manufactured by R. Lechner in Vienna, Austria.

With this instrument the camera *C*, Fig. 143, Plate LXXV, is centrally located and mounted above the horizontal circle. The telescope *F* and the vertical circle *V* are attached to one side of the camera, but counterbalanced by the weight *G*. In order to reduce the weight as much as possible aluminum has been used extensively in the construction of this apparatus. For instance the upright *T* is made entirely of that metal.

This instrument has been manufactured in two sizes; the horizontal circle of the smaller one is graduated to 30′ and the

verniers read to 1′, while the larger one has a circle graduated to 20′ and its verniers read to 20″. The telescope F is mounted somewhat like that of the Danish plane-table alidade.

The adjustment of the horizontal axis of revolution of the telescope F is accomplished by means of a special striding level. Clamps and slow-motion screws are provided for both the horizontal and the vertical circles. The telescope has a focal length of 27 cm. and an aperture of 31 mm. with a magnifying power of 9 to 18 diameters. The telescope is arranged for stadia-reading, and it has 100 as the constant multiplier. The telescope-level L is graduated either to 10″ or 20″. The vertical circle is graduated to 20′ and its two verniers read to 20″. The camera proper is made of aluminum and it is provided with a Zeiss anastigmat. By means of the rack and pinion, z, the lens may be elevated or depressed by either 30 or 50 mm., according to the size of the instrument. The scale t, together with the vernier n, serves to measure the vertical deviation of the lens from its normal position. Also this camera is provided with a metal frame the inner edges of which have either a centimeter or a 5-millimeter graduation, which is reproduced upon the negatives. This graduation serves not only to locate the horizon and the principal line upon the photographic perspectives, but it also gives ready means for discovering any distortion that may arise in the perspective, due to the wet process of development. The graduated metal diaphragm or frame is brought into direct contact with the sensitive surface of the film by a simple mechanical contrivance, in such a way that the focal length remains constant for all negatives, even if the plate-holders or plates should vary a little in thickness.

I. Phototheodolite Devised by Pollack and Hafferl.

This phototheodolite is shown in Fig. 144, Plate LXXV. It has been used under the Imperial General Directory of

Austrian State Railroads, and it was placed on exhibition during the Ninth Convention of German Geographers in Vienna in 1891. This camera has no graduated metal frame, its horizon and principal line being located by means of a set of four vanes or index marks, which are pressed against the sensitized film of the photographic plate by means of a revolving button, a device similar to that mentioned in connection with the older pattern of the U. S. Coast and Geodetic Survey camera. The instrument is leveled by means of two leveling-screws *s*, counteracted by two pivots *t*, Fig. 144, Plate LXXV, which are held in position by two spiral springs.

K. R. Lechner's Photogrammeter.

R. Lechner's photogrammeter is shown in Fig. 145, Plate LXXVI. (Lechner also manufactures Pollack's, Werner's, and Huebl's instruments.)

It is a rectangular metal camera, *C*, of constant focal length, centrally mounted upon a graduated horizontal circle, *K*. Two spirit-levels *l*, attached to the upper limb of the horizontal circle (which is graduated into degrees), and three leveling-screws *s* serve to adjust the position of the instrument. B_1 is the vertical axis of rotation for camera and horizontal circle. The tripod is set up approximately level, the circular level *x* being provided for that purpose.

The camera is connected with the upper limb of the horizontal circle by four screws. Two of these are in the direction of the optical axis and serve to adjust the image plate into vertical plane (the levels *l* reading zero), the other two are situated in a line at right angles to the direction of the optical axis; they serve to adjust the horizon line into horizontal plane.

The objective, *O*, is a Zeiss anastigmat *f*/18, and it may be elevated or depressed by means of a rack and pinion, such displacement being read on the scale, *t*, with vernier, *n*.

A metal frame with inner edges graduated in centimeters is

also provided for this camera, and a special mechanical device serves to press the plate (in the plate-holder after the slide had been withdrawn) against the rear surface of this frame so that the centimeter scale is impressed on the margin of the negative or photograph, thus providing the means to locate the horizon and principal lines upon the perspective and also to eliminate any error due either to a possible faulty or imperfect registration of the plate-holder or due to distortion in the photograph (paper print).

In the middle of the back-board of the camera is an eyepiece with cross-threads, very similar in arrangement to that described for Paganini's new phototheodolite, forming a telescope with the object-glass of the camera. In this case, however, the cross-threads are attached to the eyepiece and their intersection coincides with the principal point of the perspective.

A dial compass, *B*, is attached to the upper face of the camera-box, *a* being the catch to clamp the needle, or dial, when not in use.

L. Phototheodolite of Col. A. Laussedat (new Model).

Col. A. Laussedat's latest phototheodolite, manufactured by E. Ducretet and L. Lejeune, Paris, France, is shown in Figs. 146 and 147, Plate LXXVI. Both transit telescope and camera are centrally mounted, the latter above the former. The camera may also be separated from the transit, and by means of a special pivot or spindle s', Fig. 147, Plate LXXVI, it can then be mounted upon the same tripod. The transit may be used for trigonometric observations after removal of the camera. Fig. 146, Plate LXXVI, represents the complete instrument.

sss are the three leveling-screws and c_1 is the central clamp;

C is the camera and *B* is the magazine for fifteen plates;

O is the objective of the camera (it is a rectilinear wide angle lens of 75 millimeters focal length);

H is the sliding front plate provided with pinion and rack *R* to elevate or depress the lens;

V is a finder to show the extent of the field covered by the photographic plate, although a focusing-glass is also provided;

L is the transit telescope provided with stadia wires;

Ce is the vertical circle graduated to 30′;

MM are the uprights supporting the horizontal axis of revolution of the transit telescope and also supporting the camera;

A is the horizontal circle graduated into 30′; its clamp and slow-motion screw are shown at *P′*;

N is the adjustable level, and

D is a long compass, with slow-motion screw and clamp at *P*, to read the magnetic azimuth on the horizontal circle *A*.

Several loaded magazines, each containing 15 plates, may be carried with the instrument. The plates may be changed in full daylight without removing the camera. The plates are $6\frac{1}{2}\times 9$ centimeters. Enlarged prints are used for the iconometric plotting. Six plates forming a panorama cover the entire horizon. The lens is provided with an iris-shutter, and it may be focused for short distances or infinity by turning a lever over a scale, showing the distances in meters, attached to the front board *H*, Fig. 146, Plate LXXVI. In Fig. 147, Plate LXXVI, the instrument (camera) is represented with the magazine *B* removed and replaced by the ground glass *G*.

The entire outfit, excepting the tripod, which is carried separately, may be transported in a carrying-case (with shoulder-straps) $39\times 28\times 17$ centimeters. The weight of the carrying-case, including instrument (complete), one magazine, and fifteen plates amounts to 8 kilogrammes.

M. Phototheodolite of Starke and Kammerer.

This instrument, represented in Fig. 148, Plate LXXVII, somewhat resembles in construction the phototheodolite of Prof. Finsterwalder; neither has a vertical circle and both have a "camera telescope."

The camera is mounted on the horizontal circle like a theodolite. An ordinary skeleton tripod supports the three leveling-

screws S of the horizontal circle, Fig. 148, Plate LXXVII, and a central clamp-screw P with spiral spring connects the tripod with the instrument proper.

H is the horizontal circle, graduated to 20′; its two verniers with microscopes L read to single minutes.

The vertical axis, terminating in three horizontal arms B_1, B_2, and B_3, may be adjusted by means of the leveling-screws S and the cross-levels l_1 and l_2. The plate D, forming the support for the cross-levels, is firmly attached to the arm B_2.

E = upper clamp-screw;
M = upper tangent-screw for slow motion;
F_1, F_2, and F_3 = three leveling-screws supporting the camera-box; they rest in the grooves of the three arms B_1, B_2, and B_3;
l_3 and l_4 = cross-levels attached to the camera, as shown in Fig. 143, Plate LXXVIII, which represents the camera-box viewed from above.

These cross-levels, together with the screws F_1, F_2, and F_3, serve to adjust the photographic plate into vertical plane.

S = movable front board, or objective slide;
Q = handle to facilitate mounting of the camera;
K_1 = head of pinion to elevate or lower the camera-lens, the slide S having a corresponding rack for that purpose;
K_2 = differential pinion for slow motion;
H = clamp-screw to secure the slide S in a given position;
m (Fig. 148, Plate LXXVII) = millimeter scale to measure the vertical change of the lens from its normal or central position, the vernier n permitting such change to be read to 0.05 mm.

The camera may be securely fastened to the vertical axis of the horizontal circle by manipulating the central clamp-screw from the interior of the camera-box.

When the instrument is in adjustment the zero mark of the vernier n will coincide with the 70 mark of the scale m, and the

lens will then be in its central or normal position. The slide *S* may be moved 70 mm. up or down; from 70 to 140 the lens will be above the normal position.

The lens of this camera is a Zeiss anastigmat, *f*/18, with a focal length of about 212 mm.

The camera-lens is suitable for phototopographic purposes if the horizontal change in the distance between its second nodal point and the image plane does not exceed

0.09	0.11	0.15	0.22	0.45 mm. for distances of
500	400	300	200	100 m.

Hence, focusing may be dispensed with for general phototopographic purposes; still, in order that this camera, for special purposes, may also produce sharp and well-defined pictures of objects comparatively close to the camera, its lens has been mounted to admit a longitudinal motion, in the direction of the optical axis, within a range of 2 mm., thus giving the means to focus objects that are only 23 m. distant from the camera.

The external tube of the lens mount has a helical groove, or slot, in which a small metal block *t*, Fig. 149, Plate LXXVIII, provided with an index mark, may travel. This block *t* is attached to the inner tube of the lens mount, and a screw *r*, Fig. 149, Plate LXXVIII, at one end of the slot serves to clamp the two tubes together when the focal length is to be maintained constant for any length of time.

Loosening the screw *r* and revolving the outer tube from left to right will shorten the focal length, and when the block *t* has passed from one end of the slot to the other, the focal length will have suffered a change in length of 2 mm.

The two positions of the index mark on the block *t* for these extreme limits are marked on the outer side 0 and 2, Fig. 149, Plate LXXVIII; the interval is divided into twenty equal parts, one division corresponding with an axial motion of the camera-lens of 0.1 mm. A metal frame is attached in the rear to the

camera sides and the posterior surface of this frame coincides with the image plane. The inner edges of this metal frame are provided with a centimeter graduation, the middle marks of the two horizontal sides indicate the position of the principal line, while the middle notches of the two vertical sides mark the position of the horizon line. When the camera is adjusted these lines will intersect each other in the principal point of the photographic perspective. The inner opening of the metal frame is 17.8 and 22.8 cm., which, of course, is also the size of the pictures.

The two frames *I* and *II*, shown in Figs. 150 and 151, Plate LXXVIII, give the means to make a light-tight connection between the single plate-holders (or ground glass) and the camera-box. The short bellows *W*, connecting frames *I* and *II*, will admit the frame *II* to be moved toward or from the frame *I*, which is securely attached to the camera-box. Each one of these frames *I* and *II* is provided with two hooks; frame *I* has an upper hook h_1, Figs. 148 and 149, Plates LXXVII and LXXVIII, and a similar hook near the lower corner diagonally opposite h_1. The hook h_2, Fig. 149, Plate LXXVIII, is attached to the upper corner of frame *II*, opposite hook h_1, and frame *II* has a similar lower hook diagonally opposite h_2 and directly below hook h_1.

Fig. 151, Plate LXXVIII, represents the section of a rear corner of the camera-box, showing the ground-glass-plate attachment *V* (it also has the eyepiece forming a telescope with the camera-lens, Fig. 152, Plate LXXIX).

Frame *II* is secured to frame *I* by means of the upper left hook h_2 and the lower right hook. The ground-glass frame *V* is supported by the screws Z_1 and Z_2, Figs. 151 and 152, Plates LXXVIII and LXXIX, the points of which rest upon the metal plates π, Figs. 149 and 151, Plate LXXVIII, permanently attached to the fixed frame *I*. The face of the ground glass *G*, Fig. 151, Plate LXXVIII, is brought into contact with the rear surface of the graduated frame *R* by means of the upper right and lower left hooks.

The position of the optical axis of the eyepiece may be adjusted vertically by turning the screws Z_1 and Z_2 until the line of collimation of the eyepiece and camera-lens coincide in the horizon plane, the camera-lens being in its normal position, the zero mark of vernier *n* coinciding with the 70 mark of the scale *m*, Fig. 148, Plate LXXVII. In this position points may be observed through the eyepiece of the ground-glass attachment. When the camera-lens has been moved some distance up or down (away from its normal position), however, the eyepiece can no longer be used with its line of collimation in a horizontal position, and the clamps, or stops, p_1 and p_2, Fig. 152, Plate LXXIX, are unfastened and the eyepiece is tilted up or down—it rotates about a horizontal axis x_1x_2, Fig. 152, Plate LXXIX—until its optical axis is directed to the center of the object-glass. The image of the point to be bisected will then appear well defined.

The circular openings ρ, shown in the ground-glass attachment, Fig. 152, Plate LXXIX, serve to examine the middle notches (of the inner edges of the graduated metal frame *R*) which define the termini of horizon and principal line of the perspective. The openings ρ give the means to test the positions of those lines with reference to the middle notches; both should coincide. The outer wooden frame *V*, Fig. 151, Plate LXXVIII, of the ground-glass attachment is strengthened by two metal diagonals *D* joined into a ring at their intersection, which ring supports the eyepiece, revolvable about x_1x_2 as axis.

Each holder contains but one plate, and Fig. 150, Plate LXXVIII, shows a section through the upper rear part of the camera with a plate-holder *K* in position.

P=dry-plate;

f=springs supporting the dry-plate at its four corners;

G=hard-rubber slide, which is completely withdrawn when a plate is to be exposed;

R=graduated metal frame permanently secured to the rear of the camera-box;

C=section of camera-box wall.

To attach a plate-holder *K* to the camera, Fig. 150, Plate LXXVIII, frame *II* is set free from *I* and *K* is hung to frame *II* by means of the bent plate *l* (permanently attached to *K*) when the beveled projecting frame or edge of *K* closes into the corresponding rebate of frame *II*, producing a light-tight connection. *K* is secured to *II* with the upper left and lower right hooks, giving it the position shown in Fig. 150, Plate LXXVIII. After the hard-rubber slide *G* has been withdrawn, the second pair of hooks, upper right and lower left, are tightened to draw the holder *K* forward until the sensitive-film surface is brought into contact with the graduated metal frame *R* (at the back of the camera), the springs *f* serving as a cushion to insure a perfect contact without straining the glass plate *P*. The lens is now uncapped, the exposure made, and the holder is withdrawn by repeating the same operations in inverse order: unfastening the pair of hooks, upper right and lower left, inserting the slide *G*, and drawing back the two last hooks, lower right and upper left.

N. Capt. von Hübl's Plane-table Photogrammeter.

This instrument, manufactured by R. Lechner in Vienna, has been described in Lechner's "Mittheilungen aus dem Gebiete der Photographie und Kartographie," Wilhelm Müller, Graben 31, Wien. It is the result of Capt. Hübl's endeavors to reduce the weight and costs of an effective photographic-surveying instrument, to be easily adjusted and manipulated and to subserve topographical purposes.

As the final result, generally aimed at in topography, reduces itself to the graphical representation of the terrene, Capt. Hübl combined the surveying-camera with a plane table by means of which the directions needed for the orientation of the picture traces, as well as those required for the location of the camera station, may be plotted directly in the field. It is supposed that a sufficient number of triangulation points had been provided to locate the camera stations by resecting upon signals, of which at least three should be visible from every camera station.

For this purpose the camera top M (21×21 cm.) supports the plane table sheet, which is securely held in position by four metal corner clamps n, Fig. 153, Plate LXXIX.

C=camera-box (of constant focal length) made of aluminum;
T=graduated horizontal circle with clamp-screw. It enables the observer to turn the camera in azimuth by an equal amount (panorama section) after each successive exposure;
VV=graduated metal frame;
XX=correction screws for adjusting VV to bring the principal point into the optical axis of the camera-lens;
b=rubber bulb for operating the pneumatic shutter of the camera;
t=head of pinion, which serves to elevate or depress the camera-lens. Any such change from its normal position may be read off on a scale with vernier, secured at one side of the camera-lens;
d=spirit-level. Two are provided (at right angles) for adjusting plane table M into horizontal plane (the photographic plate will then be in vertical plane);
R=movable plate-carrier;
LL=lever to move the plate-carrier toward the lens until the sensitive-film surface of photograpic plate is brought into direct contact with the graduated metal frame VV;
K=plane-table alidade with vertical circle, arranged for stadia-reading;
Z=pivot vertically above second nodal point of camera-lens.

The lever h serves to locate the principal point f, Fig. 154, Plate LXXIX; when the edge of the alidade ruler LL abuts against the upturned lever h the principal ray zf, bisecting the angle ezg, Fig. 154, Plate LXXIX, may be drawn upon the plane-table sheet.

Fig. 154, Plate LXXIX, represents the plane-table top $abcd$; it has two pivots z and z' about which the alidade ruler LL may be revolved.

zf = constant focal length of camera;
eg = horizontal projection of the picture trace;
ezg = horizontal angle commanded by each plate = panorama section.

At e and g are two stops (corresponding to the ends of the photographic field) representing the ends of the picture trace on the plane-table sheet.

By placing the alidade ruler LL upon the pivot z the horizontal projections of lines of direction, emanating from z as a center, to such points of the landscape which serve to orient the picture (so-called reference points) may be drawn upon the paper within the sector limits ezg. The point z, marked on the sheet, may be regarded as the plotted station point. The central pivot z' serves as vertical axis of rotation for the alidade ruler LL when the horizontal directions to known points (signals over trigonometric stations, visible from the camera station) are to be plotted to locate the position of the camera station. Point z', transferred to the plane-table sheet, is regarded as the plotted station point.

zf or $z'f$ is the trace of the principal plane upon the horizontal projection plane.

The plane table M with alidade K serves to locate the camera stations in both the vertical and horizontal sense; it may also be utilized for the location of tertiary points with the stadia-rod and for sketching details in the neighborhood of the station. The horizon line and principal line may be located upon the perspectives by means of the centimeter graduation of VV, or two very fine wires may be attached to the corresponding graduation marks.

The instrument rests upon the three ends of the leveling-screws S, Fig. 153, Plate LXXIX, which fit into slots at the bottom of the camera-box, the latter being firmly united with the tripod by means of a central screw with spiral spring.

This photographic plane table is well suited for topographic reconnaissance surveys. The results obtained with it may not be

as precise as those obtainable with the more complicated and refined phototheodolites; still, it is more readily transported, is very easily manipulated, and its adjustments are not subject to frequent disturbance. The instrument is compact, well conceived, and excellently executed.

The size of the photographic plate is 12×16 cm., giving an effective picture, within the graduated margin, of 10×14 cm.

The cube-shaped camera weighs 3.5 kgr.

The packing-case (knapsack), including the entire outfit and a stout tripod (with 3 folding legs), weighs only 11.5 kgr.

The cost of this outfit in Vienna is 400 florins.

O. Phototheodolite ("Phototachéomètre") Devised by J. and H. Vallot.

In 1893, Joseph and Henry Vallot entered into correspondence with Col. Laussedat with reference to the planning of a phototheodolite, to be used in the topographic survey of the Mont Blanc mountain group. The first instrument made for this purpose did not give results with the anticipated and desired degree of accuracy; its adjustments were found too unstable for transportation in rough mountains.

Owing to the defects in this instrument three hundred plates obtained in 1893 were discarded and a new phototheodolite with a constant focal length and with vertically exposed plates was devised. J. Vallot designed the geodetic part of the instrument and H. Vallot planned the camera. The manufacture was intrusted to Brasset Frères, who succeeded in furnishing an instrument of great stability, small weight, and general excellence. It is shown in Figs. 155 and 156, Plates LXXX and LXXXI. The latter illustrates the theodolite ("tachéomètre") and the former represents the surveying-camera. Both are mounted upon the same tripod and one instrument support with horizontal circle *R* answers for both. The following desiderata have been fulfilled by the makers of this instrument:

First. In order to give the least resistance to the wind, to facilitate transportation, and to reduce the price the size of the instrument has been reduced to a minimum compatible with efficiency.

Second. To avoid vibration of the plate during exposure the component parts of this instrument have been assembled and joined together with the utmost rigidity.

Third. The instrument is well balanced to avoid strains in the instrument itself and to give the results obtainable with it the greatest possible accuracy.

Fourth. The geodetic parts of this phototachymeter have been designed with a view to give results (vertical and horizontal angles) as accurate as those obtainable with Goulier's theodolite of 10 cm. diameter, which instrument had been previously used for the triangulation of the Mont Blanc group and which was now to be replaced by this new combination instrument.

Fifth. The camera, with fixed focal length, commanding an angle of 40 centigrades above and below the horizon, was to be made of metal and the correct position of the horizon line should be readily obtainable for every photographic perspective.

Sixth. The component parts of the phototachymeter have been assembled by the makers in such a manner that all future adjustments may be dispensed with. Any discrepancy may be discovered, however, by special observations, made for testing the adjustments, which discrepancies may be neutralized by applying proper corrections to the results.

Seventh. The lens selected should be as speedy as possible to reduce the time of exposure, and the definition of all points falling within the unfavorable parts of the plates should be correct within 0.1 mm. (The diameter of the circle of diffusion $\leqq 0.1$ mm.)

Eighth. If (orthochromatic) plates give better results than

films the camera chamber should be arranged for the use of the former. The definition should be good enough to admit a twofold (photographic) enlargement with no distortion to affect the accuracy of the iconometric plotting.

Ninth. Means were to be provided to enable the operator to inspect the field under control for each exposure without having recourse to dark cloth and ground glass.

Tenth. Provision should be made to divide the panorama automatically into sections of equal horizontal extensions.

Eleventh. The exchange of plates, when photographing a panorama view, should be made without the least chance of disturbing the adjustments of the instrument.

At first Carbutt's orthochromatic films were used, and it was found that they underwent a change *retraite* during the developing process, which, however, was uniform in character, thus admitting a correction to be applied. Still, it appeared to be desirable to avoid even such a uniform change in the dimensions of the negatives, requiring a correction, and glass plates are now used altogether in Vallot's work.

The orthochromatic plates are 130×180 mm. in size, with an effective field for the perspective of 120×170 mm. These small plates do not materially increase the weight of the outfit; one cardboard box containing 12 plates weighs 1.4 kgr.

The double-plate holders (0.25 kgr. in weight) were made by Balbreck. They may be inserted into the carrier and the slides be withdrawn without imparting the least shock to the instrument.

The 18 double-plate holders, carried in a special packing-case, are numbered from 1 to 36. The plates are marked in one corner with a soft pencil before removal, giving series and number. For instance: *A*, 1 to 36; *B*, 1 to 36, etc.

While in the field, the exposed and unexposed plates (their plate-holders) are kept separated in the case by placing the ground-glass frame between them. The plates used at present are Lumière's orthochromatic, series *A* (sensitive to yellow and green).

The diagram given in Fig. 157, Plate LXXXII, represents a vertical section through the camera chamber (in the principal plane).

AB = nodal plane of the lens;
$AC = CB = 50$ mm. = range of possible vertical change of lens above or below its normal position (at C);
MN = effective vertical width of plate = 120 mm.;
A = extreme upper position of lens;
B = " lower " " "
C = normal or central position of lens;
$A'M = B'N = 1$ cm.;
$AA' = CC' = BB'$ = constant focal length = 150 mm.

The extreme vertical angle which a plate may contain will be found from

$$\tan A'AN = \frac{A'N}{AA'} = \frac{110}{150} = 0.733,$$

$\measuredangle A'AN = 40.3^G$ (centesimal graduation; $400^G = 360°$ sexagesimal graduation).

For the extreme lower position B the greatest vertical angle would be

$$\measuredangle B'BM = 40.3^G,$$

and for the central or normal position C the greatest angle above and below the horizon is found from

$$\tan C'CM = \frac{C'M}{C'C} = \frac{60}{150} = 0.4,$$

$$\measuredangle C'CM = \measuredangle C'CN = 26.2^G.$$

The horizontal field α of the plate may be found from

$$\tan \frac{\alpha}{2} = \frac{85}{150} = 0.567,$$

the effective width of plate being = 170 mm.

$$\frac{\alpha}{2} = 32.8; \quad \alpha = 65.6^G.$$

If no overlaps are required a panorama may be photographed on six plates,

$$6 \times 65.6^G = 393.6^G,$$

showing the omission of 6.4^G of the horizon. It often will be desirable, however, not only to photograph the entire panorama, but also to overlap two adjoining plates. The horizon has accordingly been divided into six equal sectors of 60^G each and a seventh sector of 40^G.

In place of the customary slide (which is either too tight or too loose and consequently not light-tight) the camera chamber has been provided with three openings (O_1, O_3, and O_2, Fig. 155, Plate LXXX), *A*, *C*, and *B*, Fig. 157, Plate LXXXII, into either of which the lens may be inserted and securely held there by a bayonet catch. The lens is secured in the middle opening O_3, Fig. 155, when the vertical angles above and below the horizon do not surpass 26^G. It is inserted at O_2, Fig. 155, Plate LXXX (at *B*, Fig. 157, Plate LXXXII), when low grounds (valleys) are to be photographed from high elevations and at *A*, Fig. 157, Plate LXXXII, when mountain peaks are to be photographed from lower stations.

The horizon line for each of these three positions of the lens is located on the negatives by a set of two projecting points *p*, Fig. 155, Plate LXXX, which are photographed on every plate.

When great differences in altitude are to be recorded, two plates may be exposed in the same direction and from the same station, one with the lens at *A*, the other with the lens at *B*, Fig. 157, Plate LXXXII.

The openings O_1 and O_2, Fig. 155, Plate LXXX, are closed by caps which have the same bayonet catch as the lens mount O_3.

The objective is an anastigmat of Zeiss, No. 2, series III*a*, with revolving diaphragm and stop No. 5 $\left(\frac{f}{40}\right)$. This lens is made of Jena glassby Krauss in France, and it has a constant focal length of 150 mm.

Enlargements of the negatives 50×60 mm. give very good results for the iconometric plotting, which has been done on scale 1:20000 for the Mont Blanc survey.

Behind the lens a yellow (plate) glass screen has been inserted with a tint sufficiently dark to necessitate the length of exposure required for the normal plate to be increased fifteen times. The insertion of this screen increases the focal length of the objective to 151 mm., the yellow light-rays being less refracted than the blue and violet rays. This camera is not provided with an instantaneous shutter, as the exposure will always require several seconds.

The tripod is made of oak and it may be folded together to 0.75 m. length. On rocky peaks, where the unfolded tripod would be too long or where it would require too much ground space, it may be used in its folded condition.

The tripod head *H*, Figs. 155 and 156, Plates LXXX and LXXXI, is made of aluminum, which metal enters greatly into the composition of this instrument. The camera chamber and lens-hole caps O_1 and O_2, Fig. 155, Plate LXXX, are also made of aluminum.

The horizontal circle and metal instrument support resembles in form the horizontal circle adopted for the tachymeter-theodolites used by the Génie Corps of France. The three leveling-screws *L*, Figs. 155 and 156, Plates LXXX and LXXXI, set into the three arms *A*, are on the circumference of a circle of 0.17 m. in diameter.

The horizontal circle *R*, Figs. 155 and 156, Plates LXXX and LXXXI, is 0.10 m. in diameter and is mounted above the circular disc *F* which supports the cross-levels l_1 and l_2, used for leveling the instrument.

Its graduation (centesimal $400^G = 360°$ sexagesimal) is on the vertical (outer) cylindrical surface, and it may easily be read when the camera is mounted on the instrument support.

A conical pinion (in the prolongation of the vertical axis) on the horizontal circle serves to support the camera or the tachymeter-theodolite, which are provided with conical bearings to fit this conical pinion.

A special arrangement with stops insures the uniform azimuthal swings of the camera when exposing the plates forming a complete panorama; six of these plates cover an angle of 60^G each and the seventh controls 40^G of the horizon. Each plate covers or overlaps the adjoining one by a common margin of 15 mm. in width. When used as a theodolite the arresting stops may be set inactive.

The definition of the photographic perspectives for all objects from 10 m. to infinite distance is very clear (using stop No. 5).

A tele-objective (long-distance objective) has been provided by means of which circular pictures may be obtained on the plate of 0.11 m. diameter and with a two and one half fold enlargement.

The metal points p and p', Fig. 155, Plate LXXX, have circular openings of 1 mm. diameter which serve to locate the horizon and the principal line on such pictures where the image of the plate has been obscured by the tint of the image close to the point.

Blackened diaphragms *D*, Fig. 155, Plate LXXX, are inserted into the darkened chamber to intercept all side-light rays that may be reflected into the camera and cause the plate to be fogged.

The heads of the three screws *S*, Fig. 155, Plate LXXX, used to secure the camera in its position on the horizontal circle, are corrugated or checked and well blackened to prevent side reflections of light-rays from their surfaces.

The ground-glass plate is used only when testing the adjustments of this instrument.

The upper face of the camera is provided with three sight-

frames V_1, V_2, and V_3, which may be revolved about their lower ends to lay perfectly flat on the camera top when not in use.

Two vertical planes containing V_1, V_2, and V_1V_3 include a horizontal angle of 60^G, the extreme width of the horizontal field for one plate. The sight-frame V_1 (near the lens) is provided with a vertical wire and the sight-frames V_2 and V_3 (at the back of the camera, Fig. 155, Plate LXXX) have three peep-sights each, which, together with the metal bridges of V_1, are disposed at such distances to correspond with the vertical angles, commanded by the lens on the plate, for the three different positions that may be given the lens. By sighting through the three peep-sights it may readily be determined into which one of the three openings (O_1, O_3, O_2, Fig. 155, Plate LXXX) the lens should be inserted to control the extension of a certain panorama section in the vertical sense.

For executing the tertiary triangulation and for locating detached camera stations (stations not already included in the triangulation scheme) the surveying-camera, Fig. 155, Plate LXXX, may be converted into a tachymeter-theodolite by replacing the camera by an "alidade holométrique" with "broken" telescope, *ab*, Fig. 156, Plate LXXXI, like that of Col. Goulier's pattern (with the exception that the ruler has been discarded here). The base of this tachymeter has three screws *S*, Fig. 156, Plate LXXXI, corresponding with those of the camera, to secure it to the horizontal circle.

The telescope, which magnifies about twelve times, is "broken" to facilitate the measuring of large vertical angles. A finder *e*, Fig. 156, Plate LXXXI, of a fourfold magnifying power is provided. It has the same form as the telescope *ab*.

Vertical angles are measured with the vertical circle *E* ("l'éclimètre"), Fig. 156, Plate LXXXI, which has a diameter of 0.08 m. and reads to single grades (quadricentesimal graduation).

A special level is supplied to facilitate the ready adjustment

of the telescope *ab* into horizontal plane when this tachymeter is to be used as a spirit-level.

This entire phototachymeter (excluding the tripod) is packed into a box having three compartments, which may be closed by two doors like a wardrobe. One compartment contains the tachymeter proper (" l'éclimètre ") *ET*, Fig. 156, Plate LXXXI, the other receives the camera *C*, Fig. 155, Plate LXXX, and the third is reserved for the repeating circle *R* with its support *A*, Figs. 155 and 156, Plates LXXX and LXXXI.

The folding tripod, together with a light folding stadia or telemeter-rod, is carried in a separate packing-case. All packing-cases are covered with rubber cloth to guard against the evil effects of dampness.

This entire instrument outfit may be strapped to a light packing-frame, making a compact pack to be carried on the back.

The weight of this outfit has been distributed as follows:

Complete phototachymeter.	5.3	kgr.
Packing-case and accessories.	3.6	"
Water-proof case, including straps.	0.8	"
Folding tripod.	4.8	"
Folding stadia-rod.	0.8	"
Water-proof case for both, including straps	0.7	"
Total weight of instruments.	16	kgr.
Packing-frame, including straps.	2	"
Total weight to be borne by one packer.	18	kgr.

The 18 double-plate holders (including 3 doz. plates) weigh 9 kgr.; they are stored in a wooden case which weighs 3.5 kgr., including the water-proof covering. These 12.5 kgr. are carried by a second packer who has additional implements to take, bringing the weight of his pack also up to 18 kgr.

For the survey of Mont Blanc it has been found that 36 plates fully suffice for a day's work. For a trip of several days'

duration the observer carries extra plates (in their cardboard boxes, but stowed away in a separate water-proof packing-case), which are exchanged every night, using a small folding ruby light and portable dark tent.

In 1894 four hundred negatives were obtained by Vallot Bros., and in 1895 the number reached over 500. The season of 1896 was so misty and rainy that few days were available for this work, the mountain peaks being rarely visible, and also lower parts of the mountains being more generally hidden from view in a dense fog. This season's results again proved the value of the phototopographic method above all others for surveys in the higher altitudes of mountainous regions, as the results obtained during the short periods of good weather could not have been acquired in the short time available by any other known topographic method.

The area of this survey is controlled by 300 triangulation points (established between 1894 and 1896) which are connected with a base line at Chamounix of 1785.824 m. length.

P. Phototheodolite Designed by J. Bridges-Lee.

This instrument has been patented in England and other countries, and it is made by Louis P. Casella, who has published a full description of the same, with instructions for its use in the field (Description of a New Phototheodolite designed by J. Bridges-Lee, Esq., M.A., F.G.S., etc. With full instructions as to its manipulation in the field. L. Casella, maker to the Admiralty, Ordnance, etc., No. 147 Holborn Bars, London, E. C.), from which the following description has been abstracted:

This phototheodolite is shown in Figs. 158 and 159, Plates LXXXIII and LXXXIV, the latter representing a view of the interior of the camera-box, the ground-glass plate *H* having been turned down. It will be noted that this instrument comprises:

(1) A complete, well-made theodolite reading to minutes;

(2) A photographic outfit answering all ordinary demands;
(3) A good and large azimuth compass, its vertical scale admitting of very close readings to be made either through the rear window h' or through the lens B.

The combination of these three instruments into a symmetrical well-made phototheodolite makes this one of the most generally useful instruments that an explorer of unknown regions can add to his instrumental outfit.

With reference to Figs. 158 and 159, Plates LXXXIII and LXXXIV, we have:

A. Rectangular camera-box made of aluminum (cast metal); its upper face supports the telescope *E*, with vertical circle *F* reading to minutes. This box is permanently attached to the leveling support T', Fig. 158, Plate LXXXIII.

B. Rectilinear photographic lens of excellent quality and supplied with iris diaphragm. No focusing adjustments are provided for this lens, and it should be set by the instrument-maker very accurately in correct position with reference to the other parts of the instrument.

A second photographic lens, movable in a sleeve with rack-and-pinion focusing adjustment, will be supplied if the instrument is to be used for ordinary photographic work at short distances.

C. Horizontal circle, graduated to half degrees with vernier reading to single minutes.

The vernier is attached to the rear of the camera, Fig. 159, Plate LXXXIV, its zero mark falling into the same vertical plane which passes through the optical axis of the camera-lens.

D. Tribrach, or triangular piece connecting tripod head and camera. It supports the terminating heads at the base ends of the three leveling-screws. To insure stability the terminal feet of the levelling-screws may be secured to the tribrach by means of the usual locking-plate connected with the tribrach.

E. Telescope with cross- and stadia-inches in the body and

general adjustments for a surveying-telescope. The telescope is mounted like that of a plane-table alidade to be rotated about a horizontal axis in a vertical plane only. Its plane of transit contains the optical axis of the camera-lens, the zero mark of the vernier of the horizontal circle, the vertical hair *K*, as well as the vertical axis of the needle support of the azimuth compass, when the instrument is in adjust ment and leveled.

F. Vertical circle, graduated into half-degrees, firmly connected with the telescope and provided with a fixed vernier reading to single minutes. This circle controls a vertical range sufficient for all ordinary topographic surveying purposes.

G. Tubular spirit-level revolvable in a low cylindrical case firmly attached to and sunken into the upper face of the aluminum camera-box. This level serves to give the top of the camera-box a horizontal position when the camera has been oriented for an exposure to be made. This adjustment is made in the usual manner by means of three leveling-screws supporting the instrument on the tribrach.

H. Back of the camera containing the ground glass *h* and supplied with hinges to enable the operator to swing the ground glass back, as shown in Fig. 159, Plate LXXXIV. A window *h′* of polished glass is inserted into the ground glass *h* to enable the surveyor to observe the vertical index hair *K* and coincident graduation mark of the vertical compass scale, with or without the use of the microscope *O*.

I. Rectangular metal frame supplied with stout backstays (not visible in the illustrations) and securely attached to the bottom plate which supports the compass box *M*. This bottom plate may be moved in the direction of the axis of the camera-lens, sliding on guides rigidly fixed to the bottom of the camera-box.

When the camera is to be used for ordinary photographic purposes the bottom plate (including the frame *I* and azi-

muth compass) may be withdrawn and laid aside. A square piece of black velvet is provided to be placed upon the metal bottom of the camera-box. After the insertion of the second lens with adjustable focal length the camera will be ready to be used for photographing near objects.

The rear surfaces of the frame *I* are in vertical plane which is perpendicular to the optical axis of the camera-lens when the instrument is leveled and in perfect adjustment.

jj. Transverse pinion extending across the bottom of the camera-box and terminating in two milled heads *JJ*. The frame *I* may be racked backwards or forwards by a corresponding turning of the milled heads *JJ*.

Pointers are attached to the milled heads, which serve to indicate whether the internal structures are in the forward or backward position when the falling back of the camera-box has been let down to allow a double-plate holder to be inserted into the camera.

The dimensions of the rectangular frame *I* are such that it can be racked back (entering the plate-holder frame) to be brought into direct contact with the sensitized film of the photographic dry-plate, when the cross-hairs *K* and *K'* will also actually touch the film. Of course, the slide protecting the photographic plate against light should be first removed before the frame *I* is racked back. Two small stops in the form of sliding bolts (not shown in the illustrations) are provided to prevent the frame *I* from being carried back too far or with too much force and to secure uniformity of the focal length for all phototopographic-plate exposures.

K. Vertical hair passing through two round holes in the frame *I* and held in position by means of small wooden pegs. When broken, a new hair can readily be inserted into the holes and secured by small pegs. This hair serves to mark on the negative the median vertical plane of the instrument and the principal line of the photographic perspective. It

cuts the optical axis of the camera-lens at right angles and it serves as index mark when the compass scale is read. It is in the same plane as the vertical web in the telescope, the optical axis of camera-lens, the vertical axis of revolution of the azimuth compass, and the zero mark of the vernier of the horizontal circle.

K′. Horizontal hair secured to the frame in the same manner as hair *K*. The point of intersection of both hairs is in the optical axis of the camera-lens, and on the negative it marks the principal point of the photographic perspective. When the camera is in perfect adjustment and accurately leveled the shadowgraph of *K′* on the negative will bisect points having the same height as the optical axis of the camera at the station whence the picture was taken.

The proper location of the small holes in the frame *I*, fixing the position of the hairs *K* and *K′*, is ascertained by the maker.

LL. Small tablets of transparent celluloid or xylonite. They serve to receive notes giving particulars concerning station mark, barometric reading, or determined elevation of camera station, number of plate, time of exposure, etc., which it may be desirable to record photographically, as shadowgraphs, on the picture. Such notes are written upon the tablets *LL* in the ordinary way with quick-drying ink. The tablets when dry are placed upside down in small pockets in the frame and the notes appear as shadowgraphs in the corners bordering the sky portion of the negative.

M. Magnetic azimuth compass with vertical cylindrical transparent scale, graduated to half degrees from 0° to 360°. This transparent scale in its revolution passes quite close to the vertical index hair *K*, without ever touching it, however. The pivot of the compass is permanently secured to the base or bottom plate already referred to, so that the cylindrical compass-scale is always at exactly the same distance from the vertical hair *K*.

When the bottom plate supporting the frame *I* and compass *M* is racked forward in the camera-box, a copper disc is automatically raised, lifting the agate cup and pressing it against the support *m* so that the compass is firmly clamped, preventing injury to the pivot and other parts of the compass during transportation. When the bottom plate is racked back to bring the cross-hairs *K* and *K′* into contact with the sensitive film of a photographic plate, the agate cup is lowered (automatically) upon the pivot and the magnetic compass assumes its natural position. The compass graduation being on a transparent cylinder, the magnetic azimuth of the principal line of every exposed plate will be recorded photographically in the sky region of the negative as a shadowgraph.

N. Catch to hold the double-plate holder in place when inserted into the camera. The frame of aluminum forming the rear of the camera-box is faced with black velvet to guard against the entry of extraneous light when the double-plate holder is in position.

O. Microscope with universal joint movement to permit of its being used either for reading the observed horizontal angles (on the horizontal circle *C* with vernier), or for reading the compass bearings through the window *h′* in the ground-glass back *h*.

P. Adjustable microscope for reading vertical angles.

Q. Clamp- and tangent-screw for arresting azimuthal or horizontal circle and giving it slow motion.

R. Clamp- and tangent-screw for camera.

S. Clamp- and tangent-screw for telescope.

T. Strong aluminum head of tripod with bronze clamping-screws for folding legs. It is supplied with transverse bars (not shown in the illustrations) of bronze, serving as attachments for chains to safeguard the instrument when in position at a station. These bars also serve to receive the hooks attached to a net into which heavy stones may be placed

to give stability and steadiness to the instrument when used in windy weather.

U. Two cross-marks on the top of the box. Their distance indicates for ordinary temperatures the permanent focal length of the camera, to be used for the negatives.

A small hook for the attachment of a small plummet is secured to the tripod head *T* in the central axial line of the instrument. The telescope is supplied with an erecting as well as an inverting eyepiece.

A color-screen of optically worked green glass may be fitted inside the sunshade of the photographic lens. Yellow or orange glass can also be supplied when desired.

Attached to the frame *I* (which carries the hairs) is a horizontal transparent scale of angular distances (Fig. 159, Plate LXXXIV), photographically prepared by aid of the identical lens and instrument which it accompanies. It is used for surveying purposes, as with its aid the exact angular distances of points in the picture—to the right or left of the principal vertical plane—may be read off directly with the aid of parallel rulers. This scale also facilitates the determination of compass errors, because if there are any points in a picture whose true bearings have been fixed with precision—trigonometrically or otherwise—it is only necessary to add or subtract the angular distances of those points, as read on the horizontal scale of angles, to or from the photographiccally recorded compass-bearings of the points, and the difference between the compass-bearings and the true bearings is the compass variation. This simple verification can be performed in office at any time. This instrument is supplied with 6 double-plate holders of good construction, to carry one dozen plates, size 5×4 in., either horizontally or vertically.

It fits easily and securely in a strong, well-made, brass-bound mahogany case with catches, lock, and key.

The double-plate holders, extra eyepiece, extra camera-lens, color-screen, and plumb-bob all fit in the same case, which for

greater security and convenience of transportation is placed into an outer sole-leather case with pack-straps.

The tripod head is provided with a metal screw-cap, a suitable protecting cover of its own, and the legs can be strapped together for easy transportation.

CHAPTER IX.

PANORAMA CAMERAS.

THE older lens types gave correct perspectives only for small angles, rarely exceeding 30 degrees, and Martens in Paris was probably the first to devise a so-called panorama camera capable of photographing wider sections of the horizon on one plate, with lenses that ordinarily would cover but a small angular field. He solved this problem by constructing a hemi-cylindrical camera with a revolvable lens plate. If the objects are far enough away to permit the use of a constant focal length of lens, and if the lens may be rotated about a vertical axis in the second nodal point of the lens system, panorama views may be obtained on a sensitized surface of a daguerreotype plate bent into a half-cylinder whose radius equals the constant focal length of the lens and whose axis coincides with the vertical passing through the second nodal point of the camera-lens.

I. The Photographic Plane Table Devised by A. Chevallier (1858).

Chevallier's "planchette photographique" may be mentioned here, as, in a certain sense, it also is a panoramic camera. In this instrument the entire panorama view was continuous and found representation on a single plate; the latter, however, was exposed in the horizontal plane. The lens axis being horizontal, a prism had to be interposed between plate and lens to bring the image into the horizontal picture plane. All verticals of the landscape converged to one point, the center of the circular horizon line. For further deails of this historically inter-

esting instrument we would refer to the publications on this subject given under French phototopographic literature.

II. The Rockwood-Shallenberger Panoramic Camera.

A horizontal section through this camera (made just above the camera-lens) is represented in Fig. 160, Plate LXXXII. It practically consists of two cameras *C* and *c*. The latter (smaller) one contains the lens *O* and is revolvable about a vertical axis passing through the latter. The main camera-box *C* forms a semi-cylinder with a sensitive film stretched over the inner cylindrical surface, and that may be unwound from the magazine roller *B* passing to the receiving roller *A* after exposure. As the small camera is revolved, the light-rays entering the lens act upon a narrow vertical strip of the film at a time. The connection between the objective end of the small camera *c* with the front board *b* of the main camera *C* is accomplished by means of a pliable light-tight fabric *e*. The lens *O* has a long focus and the panoramic perspective is entirely free from distortion, only a vertical strip of one quarter inch width being exposed at one time. The pictures are 8×40 inches and it takes from three to five seconds for the lens to complete one revolution of 180 degrees. The speed in the swing of the smaller camera is controlled by a clockwork, the rate of which may be increased or retarded at pleasure, with due reference to the changes in atmospheric conditions and character of subject.

III. R. Moessard's Topographic Cylindrograph.

The so-called cylindrograph of R. Moessard (commandant du Génie, attaché au Service géographique de l'armée) is similar in construction to the apparatus just described; this instrument, however, is specially devised for surveying purposes.

The semi-cylindrical camera-box, Fig. 161, Plate LXXXV, rests upon a tripod with leveling-screws to adjust the verticality of the axis of revolution *aa* of the camera lens *O*, which axis coin-

cides with the axis of the half-cylinder, formed by the surface of the sensitive film. For focusing purposes the latter may be replaced by a semi-cylindrical ground-glass plate. By using the sight-ruler *s* as a lever the camera-lens *O* may be rotated about *aa*, allowing the speed of motion to be controlled by the illumination of the landscape. By carefully examining the panorama through *PP′* while *aa* is being moved in azimuth, the correct timing for the exposures of the different panorama strips may be made. The space between the frame *RR* is filled in with a soft and light-tight fabric, allowing an easy play for the rotation of the objective *O*.

The upper surface of the topographic cylindrograph is provided with an azimuth compass *C* and a set of cross-levels *A* and *B*. The bent frame forming the guide for the film is supplied with graduations on the inner edges which form the margins of the panoramas. The divisions of the upper and the lower scales (horizontal) correspond to degrees in arc, while the divisions of the vertical marginal ends are graduated to read: $\frac{f}{100}$, where f=constant focal length of the lens *O* (=radius of the cylindrical sensitive surface of the film). Four movable indices are provided; two of these, *H* and *H′*, Fig. 162, Plate LXXXVI, serve to mark the horizon line of the half-panorama and the other two, *N* and *E*, serve to indicate the magnetic meridian and the magnetic east and west line, respectively, for each panorama view. The proper placing of the indices for each half-panorama may be accomplished by means of the azimuth compass *C* and sight-ruler or alidade *S*. Thus the magnetic azimuths of horizontal directions may be taken directly from the picture.

The vertical angles are readily found by means of the ordinates of the pictured points (above or below the horizon line *HH′*) measured in one hundredths of the focal length f, using the photographed scales on the vertical margins of the pictures for this purpose.

For instance, the angle of depression of the ray *Oa* (to the foot of the pictured tree *a*, Fig. 162, Plate LXXXVI) is found from

$$\tan\beta' = \frac{aa'}{f},$$

or when aa' is measured on the side scale and found to be 25 parts,

$$\tan\beta' = \frac{aa'}{100} = 0.25.$$

To determine whether the levels *A* and *B*, Figs. 161 and 163, Plates LXXXV and LXXXVI, read zero when the cylindrical film is vertical, and also to ascertain whether the indices *H* and *H'*, Fig. 162, Plate LXXXVI, representing the horizon line are correctly placed, we may proceed as follows:

A theodolite, Fig. 163, Plate LXXXVI, is set up about 10 or 15 metres behind the cylindrograph (after the back of the camera had been removed to bring the indices *H* and *H'* into view) and both instruments are leveled. After bisecting the upper edge of the cylindrograph and the telescope of the theodolite is moved in azimuth the bisection should continue, and the same should be the case for the lower surface edge of the cylindrograph. If this does not take place, then the cylindrograph should be adjusted by means of the leveling-screws until the bisection does take place and the level *A* is then changed to read zero. The theodolite is now set up in the direction of the level *A* (at one side of the cylindrograph) and the level *B* is adjusted in a similar manner as just described for *A*.

To adjust the indices *H* and *H'* into the horizontal plane containing the optical axis of the adjusted cylindrograph a comparison may be made on a cylindrograph picture showing several points of known elevations, the elevation of the cylindrograph being also known, or the theodolite may be set up with the horizontal telescope at the same elevation as the optical axis of the adjusted cylindrograph. The horizontal telescope of the theodolite is now moved in azimuth until a well-defined point is

bisected, which point may be identified on the ground glass of the cylindrograph. The image of this point on the ground glass is marked and the cylindrograph is moved in azimuth, marking the image on the ground glass in two more places. A (horizontal) line passing through these marked points should pass through H and H'.

The objective is attached to a funnel-shaped box situated within the camera (see Fig. 160, Plate LXXXII) and permitting the simultaneous exposure of a vertical strip of film of a width of but 62 mm. Points of the film that would be pictured outside of this strip cannot be acted upon by the light-rays until the objective be revolved (about the axis aa) sufficiently far to expose them to the effects of the light. After the time needed for the correct exposure of this strip (of 62 mm. width) has been ascertained (by experiment or otherwise) the correct exposure may be given the entire semi-cylinder by moving the sight-ruler S, with a quick uniform motion, about aa, from one extreme end of the film to the other. The semi-cylindrical film being 860 mm. long, each strip of the film would then have been exposed the $^{62}/_{860}$th part of the time required to make one full revolution of the objective. If one complete revolution required 10 seconds, and if the correct exposure for the strip was found to be 5 seconds, each strip would have received an exposure of $\frac{10\times 62}{860}$ seconds$=0.72$ second. To give each strip the required exposure of 5 seconds the entire revolution of the lens should be repeated $\frac{5}{0.72}$ times, or about seven times, each revolution taking 10 seconds.

These panorama instruments are not made sufficiently precise, in their present form at least, to be recommended for topographic surveys. Moessard's cylindrograph, however, is well conceived, and where the transportation is an easy one, the topographic cylindrograph, in a more perfected form, may give results sufficiently accurate for surveying purposes.

CHAPTER X.

ICONOMETERS AND PERSPECTOGRAPHS.

UNDER iconometers we comprise a series of instruments which have been devised to simplify the constructions of phototopographic plotting or iconometry.

After two drawing-boards have been covered with paper (gummed down on the edges), both sheets are provided with a chart projection upon which all trigonometric (triangulation) points are plotted and their elevations inscribed.

The construction incidental to the iconometric plotting of the phototopographic survey may be divided into three classes:

First. The plotting of all horizontal directions that had been observed, instrumentally, for the location of the camera stations and for the orientation of the panorama views.

Second. The determination of the horizontal projection of points pictured on three or more photographs, taken from different stations.

Third. The determination of the elevations of the various camera stations and tertiary points that are located iconometrically to facilitate the plotting of the horizontal contours of the terrene.

I. Graphic Protractor (of L. P. Paganini).

With the aid of a specially constructed protractor, Fig. 164, Plate LXXXVII, and tracing-paper the directions obtained with the theodolite or transit in the field can readily be plotted

upon both the working- and chart-sheets. This protractor, represented in Fig. 164, Plate LXXXVII, consists of two concentric rings *AA* and *BB*, the former being movable within the latter about the common axis *C*, secured in the center of *AA* by means of the plate *aa*. The rotary motion is applied to *AA* by means of two projecting ribs *as* and *sa* on the plate *aa*.

The inner circle *AA* has a graduation divided into degrees and half degrees, while the outer circle *BB* bears a vernier *n*, reading to half minutes, the zero of which lies in the prolongation of the fiducial edge of an arm *bb*, the latter being permanently secured to the outer circle *BB* and in a radial position to the same. The clamp-screw *P* serves to hold the two circles in any position.

An alidade ruler, *DD*, the fiducial edge of which also passes through the center *C*, common to both circles, is revolvable about the axis *C* and it may be moved over the upper surfaces of the two circles *AA* and *BB*. This ruler, *DD*, bears a vernier *n'*, graduated like *n* to read to half-minutes and its zero coinciding with the fiducial edge of *DD*. The clamp-screw *P'* serves to clamp this movable arm *DD* to the outer circle *BB*.

The axis *C* has a conically shaped hollow interior, at the bottom of which a thin piece of isinglass or horn is secured in such a manner that it may be removed for renewal whenever the small puncture indicating the center of the circles and axis of revolution be worn too large.

When using an ordinary protractor to lay off the various directions (radials, that were observed with the transit in the field) from one camera station, much valuable time will be absorbed in making the additions and subtractions (which have to be made in order to obtain the actual values for the successive angles between such lines of direction), particularly when a series of panorama stations are to be plotted.

The protractor, as shown in Fig. 164, Plate LXXXVII, may be used not only as an ordinary protractor—by bringing the zeros of both circles to coincide and clamping the two circles

in that position, by means of the clamp-screw *P*—but it may also be used to plot the directions upon the map or working-sheet in the same manner as they were obtained in the field with the transit; that is to say, they may be referred to zero or to any other direction as the beginning, and then be plotted in successive order.

To do this, the inner circle is revolved until the zero of *BB* (vernier *n*) gives the same reading upon the graduation of the movable circle *AA* as the recorded reading on the transit for the prime direction. Now both circles are clamped together by means of the clamp-screw *P*. The line of prime direction is drawn along the fiducial edge of the fixed ruler *bb* upon the working-sheet (or upon tracing-paper if the station is to be located or fixed upon the tracing of the lines), the center *C* of the instrument coinciding with the point representing the station upon the paper.

The zero of the vernier *n'* of the alidade *DD* is then brought successively (upon the inner-circle graduation) to the readings of the other directions which radiate from the plotted station point at *C*, each direction being plotted in successive order by drawing a pencil line along the edge of the alidade *DD*. Care must be exercised not to change the primary position of the instrument as defined by the first line during all subsequent motions of the alidade ruler *DD*.

With the aid of this instrument the radials from the plotted camera stations may be obtained with rapidity and accuracy. If we have a sufficient number of directions to well-determined points which are evenly distributed about the station, their corresponding intersections upon both drawing-boards may be plotted with as much rapidity and accuracy as a graphical plotting will admit of.

This protractor may also serve to locate points on the construction board that, on account of importance or for reasons of control, had been bisected from several stations with the transit, and also, as will be shown, to orient a perspective view

(the picture trace) upon the board, if such perspective contains no triangulation point, or when the picture of such point is blurred or not sufficiently well defined to be identified with precision.

After all stations, including such secondary and tertiary points that were determined by transit observations from the several camera stations, have been plotted upon the two boards, the work of iconometrically determining, upon the working-sheet, such points as seem needed to complete the map is taken up. For this purpose the various elements of the perspectives are tested and corrected, if needed, after the manner previously described, and all tertiary points are selected, identified, and marked, searching for well-defined points common to two or more plates, carefully selecting therefrom only such as appear to be the most useful, either for drawing the contours or for tracing the general trends of mountain ranges, torrents, and streams, boundary lines of glaciers, etc., the number to be selected depending greatly upon the character of the terrene, upon the adopted scale, and upon the accuracy to be attained. All tertiary points are marked upon the prints (perspectives) by numerals, letters, or symbols in red ink.

II. L. P. Paganini's Graphic Sector ("Settore Grafico").

Instead of actually drawing the horizontal projections of all perspectives (the picture traces) upon the working-sheet, much time may be saved by using the instrument represented in Fig. 166, Plate LXXXVIII, devised by Paganini, who termed it "*settore grafico*," or *graphic sector*. With this graphic sector the horizontal directions to points marked upon the prints may be drawn directly on the horizontal plan without first drawing the picture traces.

In Fig. 165, Plate LXXXVII,

V represents the station, plotted on the working-sheet;

OO' the horizontal projection of a perspective (the picture

trace, oriented with reference to the plotted triangulation point S);

f = focal length for the perspective OO';

P = principal point (of view) of the perspective;

Ps upon OO' is the measure of orientation of the perspective, corresponding to the azimuthal angle ω;

VP is perpendicular to OO' and $=f$.

We now prolong VP beyond V by $VP = VP' = f$ and erect a perpendicular to $VP' = O'''O''$ in P'. Produce, likewise, VB, VA, VS to their intersections with $O'''O''$, which intersections are marked b', a', and s', respectively.

$$VP' = VP$$

and $$OO' \text{ parallel to } O'''O'';$$

hence the rectangular triangles $VP'a'$, $VP'b'$, and $VP's'$ are congruent with VPa, VPb, and VPs respectively. Therefore

$$P'a' = Pa = x,$$
$$P'b' = Pb = x'$$

and $$P's' = Ps,$$

giving also the measure of orientation $(=\omega)$ of the perspective of the picture to the picture trace.

The screw e serves to clamp the screw m whenever the position of T with reference to V is to be fixed, after it has been brought to the desired distance from the center of rotation V. Two thumb-screws W and W' (with hollow centers into which fine needles may be inserted to hold the sector in place after having been adjusted over a plotted station) serve to secure the metal sector in any desired position upon the drawing-board.

The arc SS' of the sector is graduated to ten minutes, and the zero of this graduation coincides with the axis VP of the instrument, giving readings from 0° to 25° to either side of VP.

The ruler or alidade RR' is provided with a vernier V, by

means of which the arc readings may be obtained within 30 seconds. The thumb- or clamp-screw *Z* of the alidade has a counter plate at its lower end to secure the end *R′* of the alidade ruler upon the arc *ss′* of the sector and upon the steel ruler *T*.

In order to draw the lines of direction upon the construction board to a point of the terrene (the picture of which had been identified and marked upon the perspective) the instrument is placed with its center of rotation, *V*, over the needle, marking the camera station on the working-sheet, and the button *r* is given a quarter-turn (care must be taken that the side bearings of the button *r* of the instrument may have no loose play about the needle), then *T* is moved by turning the screw *m* until *OO′* is distant from the center *V* by $VP=f$, whereupon the orientation of the instrument is accomplished as follows:

RR′ is to be directed to bisect a plotted triangulation point the image of which appears on the perspective sufficiently distinct to serve as a reference point; its abscissa is taken from the photograph by means of a pair of dividers and plotted, in the inverse direction, upon the line *OO′* from the puncture, marking *P*; the alidade ruler *RR′* is now gently brought into contact with the other point of the dividers and it is secured in this position by clamping *Z*.

Now the entire instrument is revolved about *V* until the end *R* of the alidade bisects the plotted triangulation point, when *VP* will indicate the direction of the principal line and *OO′* will be parallel to the picture trace, which really would fall beyond *V* at a distance from $V=VP=f$.

The instrument is secured in this position by gently turning the screws. The construction of the graphic sector, Fig. 166, Plate LXXXVIII, is based upon the preceding consideration, and it serves to draw from the station point *V*, on the horizontal plan, the various horizontal directions to points pictured on the panorama views.

The metal plate *VSS′*, shaped like a sector, may be revolved on the surface of the working-sheet, about the center of a

needle, puncturing the plotted station in the center *r* of the sector.

This needle passes through an oblong opening (of the same width as the diameter of the needle) of a revolvable button at *r*, secured in *V*, and through a similar slot at *V* in the metal sector plate *VSS'*. The metal ruler *RR'* is revolvable about *V*, gliding with the end *R'* over the arc *SS'* of the sector plate. The fiducial edge of the ruler *RR'* passes through the center of *V* or *r*, where it is secured to the revolvable button *r* by means of a cylinder, the bottom of which is provided with a slot similar to those in the button *r* and sector plate just mentioned.

When the ruler *RR'* and the button *r* are in a certain position these three slots (in sector plate, button, and ring of ruler) will coincide, one falling above the other, and the needle may then be inserted through the three superimposed slots into the station point under *V*, the center of rotation. By a quarter-turn of the button *r* the needle will become inclosed in a square, of which the needle circumference will form the inscribed circle. The entire instrument may now be revolved about the needle center in *V*.

The lever-screw *m* serves to move the steel ruler *T* parallel with itself and vertical to the axis *nn'* of the screw *m*. The axis of the screw *m* coincides with the direction of the central axis of the sector which passes through *V* and the middle of the arc *SS'*. When *m* is turned the ruler *T* glides up or down, its ends moving along the grooves *u* and *u'*, the inner edges of *u* and *u'* being graduated, so that the distance of the edge *OO'* of the ruler *T* from *V* may be read off to 0.1 mm.

If the edge *OO'* of the steel ruler *T* is brought to a distance $VP = f$ from the camera station in the center of *V*, by turning the screw *m* it will represent the trace of a picture with the focal length *f* (in inverse position, however, as it will correspond to the horizon line as viewed upon the ground-glass plate of the camera) (see Fig. 165, Plate LXXXVII).

The point *P*, intersection of the axis of the instrument with

OO′, will represent the principal point, plotted in horizontal plan. It is marked on the edge of *OO′* by a small conical cavity to receive the point of one arm of the dividers when the abscissæ of pictured points are transferred from the horizon line. *W* and *W′* are now pressed down, whereby the fine needles in the centers of *W* and *W′* are pressed into the working-sheet. The end *R′* of the alidade is now released and the abscissæ of all points, identified and marked on the perspective, are transferred to the line *OO′* from *P*, by means of the dividers, in their successive order but in inverse direction (the fiducial edge of the alidade *RR′* being gently brought into contact with the point of the dividers each time), and the lines of direction are drawn along the fiducial edge of the ruler end *R* with a well-pointed hard pencil.

Should the image of the triangulation point be indistinct or appear blurred upon the perspective, the instrument will have to be oriented upon the drawing-board by means of the angle of orientation ($=\omega$) of the photograph, which angle had been observed in the field (in the Italian survey that angle is recorded in the field book, Model I, Chapter VIII).

The end *R′* of the alidade is placed and secured in such a position that the fiducial edge of *RR′* forms the angle ω with the axis *VP* of the instrument, which angle is laid off (in the inverse direction of the one observed) on the arc *SS′* of the sector by means of the vernier *v*. The instrument is then revolved about the needle in *V* the same as before, until the end *R* of the ruler passes through the trigonometric point in question marked on the plotting-sheet. The instrument having been secured in this position, by turning the screws *W* and *W′*, is used in the same manner as just now described for drawing the radials which served to locate the pictured points on the plan.

If a plate had been exposed while the vertical thread (principal line) bisected a triangulation point, the angle ω becomes zero and the orientation of such photograph trace on the plotting-sheet may be accomplished by bringing the zero of the

alidade vernier v to coincide with the zero of the arc graduation, SS', clamping RR' in this position and directing the end R of the ruler to bisect the plotted triangulation point in question and securing the sector upon the working-board in this position.

Should, finally, the perspective of which the trace in horizontal plan is to be plotted contain no images of points previously located and plotted, then the zero of v is again made to coincide with the zero of the arc SS' and the instrument is revolved about the center of the needle V until the fiducial edge R of the alidade coincides with a line that had been drawn from the plotted station by means of the graphic protractor previously described, which forms in V (station point) an angle with the horizontal direction to some triangulation point observed in the field and equal to the angle of orientation $(=\omega)$ of the plate. This angle is taken from the field note-book (Model I, Chapter VI, I–*C*–6) and laid off on the sector in the inverse direction and the sector is again oriented in the manner shown before.

After the horizontal directions to the different points, identified on the panorama pictures, have been drawn with the graphic sector, they are provided with numerals or symbols to correspond with the designations affixed to the points upon the panoramic views, in order to facilitate their identification when seeking for the subsequent intersections with radials to the same points from other camera stations. The positions of the secondary and tertiary points on the plotting-plan are secured by intersections, as has been described in the preceding chapters, and they serve to make up the control of the map. It is well to transfer to the final drawing by means of tracings, which are oriented with reference to the plotted triangulation points and previously located camera stations, all the different points obtained by intersections upon the construction board, in order to erase therefrom all lead-pencil lines which served for their determination, to obscure as little as possible subsequent constructions for the location of the positions of other points of the terrene.

III. L. P. Paganini's Graphic Hypsometer ("Squadro grafico").

After the plotting of the positions of the more important secondary and tertiary points, in the horizontal sense, is well under way, it remains to ascertain the elevations of the various stations, including the secondary and tertiary points of the perspectives, in order to enable the draughtsman to interpolate the contours between the plotted points that control the terrene forms of the area to be mapped.

The elevations of all plotted camera stations may be ascertained by aid of Paganini's graphic hypsometer, Fig. 167, Plate LXXXIX, using the plotted distances between the camera stations and surrounding triangulation points and the corresponding angles of elevation, which had been observed to the latter from the camera stations and which are recorded in the field note-books (Model No. I, Chapter VIII).

The elevations of all secondary and tertiary points may be determined with the same instrument by means of their graphically measured distances from the camera stations and their corresponding ordinates (y) measured on the perspectives.

Two rulers LL' and MM', Fig. 167, Plate LXXXIX, may be made to glide with their ends L' and M' along a ruler AB, always maintaining a position perpendicular to the latter, however, for which purpose their ends are secured to two sleighs L'' and M'' which fit into two parallel grooves g and g'. The motion of LL', or rather L'', is free, and it is accomplished by pushing the button O up or down the ruler AB.

M'' is provided with a ratchet and pinion P. By turning the latter in one direction or in the other the ruler MM' will be gradually moved up or down AB, as the latter is provided with a row of teeth into which the ratchet-wheel of M'' bites while P is being revolved.

The alidade ruler $d'd$ is secured with one end, d, in V in such a manner that dd' may be freely revolved about the axis of V

as a center, while the other end, d', passes over a graduated arc Ggg'. The plug in V is similarly constructed as the one in V of the graphical sector, Fig. 166, Plate LXXXVIII (it is provided with a revolvable button containing a slot, in such a manner that the ruler AB may be revolved simultaneously with the alidade $d'd$ about a needle, marking the station point on the construction board). In this instrument the plug, the revolvable button, and the alidade ruler dd' have each a slot which intersect each other in the center of rotation V, and through which the needle marking V may be passed when they all have a certain position, the needle being again secured in place by a quarter-turn of the button. The entire instrument may be revolved about the needle in V, the center of which lies in the directions of the fiducial edges of the ruler AB and alidade dd'.

The alidade ruler dd' is provided with a vernier n, graduated to read to 30 seconds on the graduation of the arc Ggg'. This vernier serves to lay off angles from V included between the fiducial edges of AB and dd'. When dd' is brought close to and in contact with AB, the zero of the vernier n and the zero of the arc graduation Ggg' will coincide. The axis of the instrument is represented by that edge of AB (facing dd') which passes through the center of rotation V, and which passes through the zero of the graduated arc Ggg'; it also passes through the point p of the line pq, which is marked upon the ruler MM', and it is provided with a millimeter graduation. This line pq corresponds with the zero of the vernier n', which is attached to MM' and which glides along AB with MM' when the latter is moved up or down the ruler AB. AB is provided with a millimeter graduation also, and by means of the vernier n' the distance pV of the line pq from the center of V may be read to 0.1 mm.

When the line pq is brought to the distance $= f$ from V, by means of the fine ratchet movement at P, the line pq may be regarded as the axis of abscissæ drawn upon the perspective, while the point p will then represent the principal point of the perspective (see Fig. 168).

In this case the line pq may also be regarded as the axis of ordinates of the perspective mn, Fig. 168, Plate LXXXX, provided the principal plane (containing VP and the axis of ordinates) is supposed to have been rotated about VP until it coincides with the horizontal plane VPO'.

The point p is permanently marked upon the line pq (in the same way as described for the graphic sector) by a small puncture, which likewise serves to receive one point of the dividers, when such are used to lay off the coordinates, taken from the perspective.

After pq has been secured, at a distance $=f$, from the center V and the abscissa x of a point a, taken from the perspective mn, Fig. 168, Plate LXXXX, has been transferred to the line pq from p, the second point of the dividers, upon pq, will represent the horizontal projection a' of the point a. If we now move the alidade dd' until its fiducial edge touches the second point of the dividers, the triangle formed by the edge of the alidade $d'd$, the edge of the ruler AB, and the line $a'p$ will represent the horizontal triangle VPa' of Fig. 168, Plate LXXXX.

The end d' of the alidade is provided with a steel index mark i, which may be moved along dd' by means of a revolvable button, E, ending in a ratchet-wheel below, which rotates in a row of teeth attached to one side of the groove $s's$. If this index mark i is moved to a' (the intersection of the fiducial edge of the alidade dd' and line pq), the distance Va' (cut off on dd') will represent the horizontal distance of the point a' (of the perspective mn) from V (i.e., the value d in Fig. 168, Plate LXXXX) measured on the scale with which the fiducial edge of dd' is provided. Maintaining the index mark i (Fig. 167, Plate LXXXIX) in this position on dd' and revolving $d'd$ about V, until its fiducial edge coincides with the edge pV of AB, then moving the ruler MM' away from V (by turning the button P) until the line pq coincides with the index mark i, we will have transferred the distance d (Fig. 168, Plate LXXXX) upon the axis of the hypsometer; we will also have brought the line pq (engraved upon MM') to a dis-

tance equal to d from the center of rotation in V, and by transferring the ordinate y (Fig. 168, Plate LXXXX), measured on the perspective mn with a pair of dividers, upon the line pq (while the latter is still in the position just described), by inserting one point of the dividers into the cavity p and bringing the fiducial edge of the alidade dd' gently into contact with the other point of the dividers, resting on the line pq at a' (Fig. 167, Plate LXXXIX), then the triangle Vpa' of the hypsometer will also represent the vertical triangle $Va'a$ of Fig. 168, Plate LXXXX, except that now it has been revolved about Va' into the horizontal plan.

The movable ruler LL', which also remains always perpendicular to the hypsometer axis (Vp) like MM', consists of two plates firmly joined together at their ends, between which the alidade $d'd$ may freely glide when revolved about V. The upper plate of LL' is slotted like the handle of a penknife and the edges Ll and Ll' are beveled and provided with a millimeter graduation, the numerals of which correspond with a scale of $\frac{1}{50000}$ (50 m. = 1 mm.). A ratchet-screw c serves to move a plate KOK', with two index marks K and K' that may be adjusted to coincide with the intersections of the fiducial edge of the alidade dd' and the two graduated and beveled edges Ll and Ll'. The index plate KOK' has a double vernier, n'', on the opposite side of the ratchet-screw c, graduated to read $\frac{1}{50}$ millimeter (i.e., to read single meters for the $\frac{1}{50000}$ scale) in connection with the millimeter scales Ll and Ll'.

When the zeros of the double vernier n'' coincide with the zeros of the graduated edges Ll and Ll', the marks K and K' of the double index will coincide with the edge Vp of AB (i.e., with the axis of the instrument) and also with the fiducial edge of the alidade $d'd$, the zero of the vernier n also coinciding with the zero of the arc graduation Ggg' (i.e., the fiducial edge of dd' will fall together with the axis pV of the instrument).

In Fig. 168, Plate LXXXX, A may represent a point of the terrene the image of which is designated in the perspective mn by a. If A' be the orthogonal projection of A in the horizontal plane passing through the second nodal point V, then AA' will represent the difference of elevation $=L$ between the points A and V. $A'V$ will be the horizontal distance $=D$ of the point A from the camera station V, which distance is represented by $\frac{D}{50000}$ for a scale of map of $\frac{1}{50000}$.

Returning to Fig. 167, Plate LXXXIX, we now imagine the hypsometer revolved about the needle center in V until the hypsometer axis pV passes through a plotted point A' in the drawing. If the ruler MM' had previously been secured in such a position that the distance pV of p from center of station V is equal to d and if dd' had been set to lay off the ordinate y upon pq from p, and if we now bring the index mark K in a position to mark the intersection of the fiducial edge of the alidade dd' with the edge Ll of LL', then the triangle VAA', Fig. 167, Plate LXXXIX, will also represent (in the scale of 1:50000) the triangle $VA'A$ of Fig. 168, Plate LXXXX.

The index mark K indicating, on the beveled graduated edge Ll, the length $\frac{L}{50000}$, we find the difference of elevation between the point A and camera station V by reading the corresponding vernier of the double vernier n''.

The triangles Vpa' and $VA'A$ (Fig. 167, Plate LXXXIX) being similar, we will have

$$\frac{AA'}{VA'}=\frac{Pa'}{Vp}=\frac{y}{d}.$$

We know that

$$\frac{y}{d}=\frac{L}{D},$$

hence

$$\frac{AA'}{VA'}=\frac{L}{D}, \quad \text{and as} \quad VA'=\frac{D}{50000},$$

we have

$$AA'=\frac{L}{50000},$$

$$L=50000\times AA'.$$

The numerals of the graduation of the edges Ll and Ll' and of the double vernier n'' give the value AA' already multiplied by 50000, which is the true difference of elevation.

With reference to Fig. 168, Plate LXXXX, we have

$$\tan\alpha=\frac{L}{D}=\frac{y}{d}=\frac{AA'}{VA'}.$$

Hence if we know the angle of elevation of a point A of the terrene we need only to lay off this an le upon the graduated arc Ggg' by means of the alidade vernier n, from g and place the index mark K upon the intersection of the fiducial edge of the alidade dd' and edge Ll (the instrument having been placed upon the plotting-sheet in such a position that the hypsometer axis pV passes through the station V and the plotted point A'), and then read off on Ll and corresponding vernier n'' the difference of elevation between camera station and point A.

This case becomes very much simplified when the image A' of A is bisected by the principal line of the perspective (axis of ordinates), as then

$$x=o \quad \text{and} \quad d=f.$$

The alidade dd' is placed so as to lay off the ordinate of the point a upon pq from p, after the ruler MM' had been secured in a position at a distance $=f$ from V; then the index mark K

or K' is brought into the point of intersection of the fiducial edge of dd', with the edge Ll or Ll' of the ruler LL' (the axis of the hypsometer passing through the plotted point A'), and the difference of elevation between A and V is read off, either on the vernier corresponding to the graduation Ll, or on that corresponding to the graduation Ll'.

The corrections for curvature and refraction, to be applied to these differences of elevation, are taken from the ordinary field tables.

IV. The Centro-linead as Used by Capt. E. Deville.

Reference to this instrument has already been made under the head of Photograph-board, Chapter VI; it is used in Canada under Capt. E. Deville.

We had seen that the distance between the principal point and the vanishing points of lines increases the nearer parallel to the picture plane such lines would become. Lines parallel to the picture plane have their vanishing points at infinite distance from the principal point; practically they have no vanishing points. Their perspectives are parallel with the original lines.

In iconometric plotting it frequently occurs that the vanishing points of some lines fall outside of the limits of the drawing board, and in order to draw a line which if produced would pass through the distant vanishing point, special constructions would have to be made to locate the direction of such a line.

To avoid making such auxiliary constructions on the photograph board Capt. Deville uses the so-called "centro-linead," with which a line vanishing at any distant point may be drawn upon the picture plane no matter how far off from the principal point of the perspective the vanishing point may be.

This instrument, represented in Fig. 169, Plate LXXXX, is composed of a straight edge L (of wood) and two wooden movable arms l and l'. The inclination of these arms l and l'

against the straight edge may be varied to any angle. The arms may also be permanently fixed in any position by means of the clamp-screws *r* and *r'*.

We had seen that the photograph-board, Fig. 68, Plate XXXV, was provided with four points *ABC* and *E*, indicating the centers of the studs against which the arms *l* and *l'* of the centro-linead play or rest when the same is used on the photograph-board. The distance between these studs may vary. Each two forming a pair are generally placed from six to eight inches apart, and the arms of the centro-linead being held in contact with the studs, the various directions of the ruler *L* will intersect each other in one common point.

Referring to Fig. 170, Plate XCI,

A and *B* may represent one pair of studs, fixed upon the board;
OA and *OB* the arms of the centro-linead, clamped in the positions indicated, and
OC the ruler of the centro-linead.

If we describe a circle through the three points *A*, *O*, and *B*—the angle *AOB* remaining constant—the angle *AOB* will be an angle of the periphery *AB* for any position given the ruler *L* (or *OC*) as long as *l* and *l'* (*OA* and *OB*) remain in contact with *A* and *B* (the two studs on the periphery of the circle). When *OC* is changed to the position *O'C'* the intersection *V* of the two lines *OC* and *O'C'* will also be on the periphery of the circle because the angle *AOV* (*AO'V*) remains the same and must subtend the same arc *AV* as long as the position of the studs remains unchanged. Hence for the assumed position of the studs the directions of all lines drawn along the fiducial edge of the ruler *L* (giving *O* all positions on the arc *AOB*) will pass through the point *V*; they will vanish at *V*.

In the iconometric work of the Canadian surveys the centro-linead is used only for drawing the perspectives of horizontal lines whose vanishing point is on the horizon line. The studs *A* and *B* are placed on the photograph-board on a line *AB* per-

pendicular to the horizon line and at equal distances from the latter. The horizon line (DD', Fig. 68, Plate XXXV) HH', Fig. 170, Plate XCI, becomes a diameter of the circle $AOBV$ and $VA = VB$.

If the arms l and l' of the centro-linead include the same angles with the ruler L, the line OC, bisecting the angle AOB, must pass through V midway between A and B.

The distance of the vanishing point V from the principal point P may be varied at pleasure by changing the inclination of the arms l and l' against the ruler L. When the directions of the arms l and l' fall together and are perpendicular to L, the vanishing point will fall at infinite distance from the principal point P, and the lines drawn along the ruler L will be parallel to the horizon line.

The distance of the vanishing point V from P may also be varied by changing the distance between the studs A and B, or C and E, Fig. 68, Plate XXXV; increasing this distance enlarges the circle $AOBV$ and V moves farther off from P; reducing that distance decreases the diameter of the circle $AOBV$ and V will approach the principal point P. The practice in Canada, however, is to retain the position of the studs unchanged on the photograph-board and to change the inclination of the arms l and l' of the centro-linead instead.

If we gradually close the arms l and l', V will approach the line AB, and when the angle AOB becomes equal to 90° the arc AOB will have become a semicircle and the intersection of AB with HH' will be the center of the circle $AOBV$, the distance of both O and V from AB will be equal to $\frac{AB}{2}$; continuing to close the arms l and l', V will approach closer to AB without ever reaching it.

A. To Set the Arms l and l' of the Centro-linead if the Direction to the Vanishing Point be given by a Line in the Ground Plan.

In Fig. 171, Plate XCI,

P = principal point on the photograph-board;
A and B = positions of the two studs;
Sv = given direction of the line on the ground plan, when V will be the vanishing point for that line.

If we revolve the picture plane about the horizon line as axis into the horizontal plane the station may fall in S, Fig. 171, Plate XCI, when SP will represent the horizontal projection of the principal ray or the distance line (focal length) of the picture. If the point V would fall upon the drawing-board we could describe a circle through AB and V and place the fiducial edge of the ruler upon DP (the horizon line) with the axis of rotation o of the arms l and l' in D upon the circle, bring the arms l and l' into contact with the studs A and B and clamp them in that position. In this case there would be no use for the centro-linead, however, as V is accessible.

If we join VB, the angle VDB—the inclination of the lower arm l' against the ruler L—is equal to VBA, both angles subtending equal arcs of the same circle. Draw the lines CS and BS. At any point c on CS draw cM and cv parallel to AB and DP and join b and v. By reason of similarity of triangles vb must be parallel to VB and the angle

$$vbc = VBC = BDV.$$

Hence the arms of the centro-linead may be set, in the case under consideration, by placing the ruler L on Mb, the axis of rotation, O, coinciding with b and adjusting the lower arm l' of the centro-linead to coincide with bv. The other arm l, having the same inclination against the ruler L as l', may be set by placing

the ruler L upon the horizon line DP and moving it along this line until the lower adjusted arm l' comes into contact with the stud B, then moving the other arm l about O until it comes into contact with the stud A and clamping it also.

The lines BS, CS, Mc, and cv are drawn once for all upon the photograph-board, Fig. 68, Plate XXXV. The only line to be drawn for setting the centro-linead arms is Sv, which is the direction of the given line on the ground plan. The line bv need not be drawn, the points b and v being located by drawing cv parallel with the horizon line and cM or cb parallel to the distance line SP.

B. To Set the Arms of the Centro-linead if the given Line (VE) belongs to the Perspective.

Take any point F, Fig. 172, Plate XCI, on the horizon line, join F with E and F with B, then draw cM parallel to AB. Through e draw ev parallel to EV and join vb. Owing to the similarity of triangles vb will be parallel to VB and the angle

$$vbc = VBA,$$

which is the inclination of the arm against the ruler L of the centro-linead. The lines FB and cM are permanently laid down on the photograph-board, Fig. 68, Plate XXXV, but FE and ve will have to be drawn for every given line; in this case two lines will have to be drawn instead of one as in the preceding case.

Centro-lineads are usually sold in pairs; one serves to work on the left side of the principal point and the other on the right.

V. The Perspectometer as Used by Capt. E. Deville.

The perspectometer serves to dispense with the construction of the squares on the perspective, when using the method of squares (Chapter IV), to draw a figure in the

ground plane by means of its perspective. On a thin transparent film (glass, xylonite, isinglass, horn, etc.) two parallel lines AB and DD', Fig. 173, Plate XCII, are drawn intersecting the common perpendicular pP. Make $DP = PD' = pA = pB =$ distance line (focal length) and from p lay off on AB (to both sides of p) equal distances,

$$pm = mn = no \ldots = p'm' = m'n' = n'o' \ldots.$$

Join these points of division to P and through the corresponding intersections of the radials from P with AD and BD' draw lines rr', tt' . . . , which lines will be parallel to AB and DD'.

Use of the Perspectometer.—The instrument is placed upon a perspective with P on the principal point and DD' coinciding with the horizon line. The ground line of the perspective may fall in XY; it is divided into equal parts by the radials from P, and the trapezoids of the perspectometer represent the perspectives of the squares in the ground plane having the equal parts of XY as sides.

By placing the perspectometer on the perspective in the manner indicated above, the squares covering the perspective of the figure, which is to be plotted iconometrically on the ground plan, are at once apparent and only those needed are drawn on the ground plan.

The sides of the squares to be drawn on the ground plan (their side lengths are equal to the divisions on the ground line between the radials trom P) are laid off from the trace of the principal plane on the ground line, and the position of the front line nearest the picture trace (or ground line) is laid off on the ground plan either by estimation or by construction. The estimation of the position of this line (corresponding to tt') on the ground plane is made by noting the fraction of a square's side which represents the distance (between tt' and XY, Fig. 173, Plate XCII) from the ground line on the perspective.

The perspectometer serves only for perspectives which have

the same distance line (like photographs of distant objects taken with the same lens), different distance lines requiring a new perspectometer to be constructed for every one.

The width pP should be equal to the height of the horizon line above the foot of the picture; the radials need not extend beyond the width of the picture, the distance points D and D' having been taken as the limit of the perspectometer in the figure (Fig. 173, Plate XCII) merely to show more fully the principles involved in its construction. The length of a single division on the line AB should be selected with reference to the resultant equal division lengths of the lowest ground line used for the pictures, as the divisions on the latter give the measure for the sides of the squares to be drawn on the ground plan.

These division lengths on the ground line should be in harmony with the scale of the plan and with the degree of accuracy that may be required for the delineation of the topographic features. The smaller the size of the squares on the ground plan selected the more accurately the transfer to the ground plan of the figure from its perspective may be made; the same principles being involved in this method of iconometric plotting as in the well-known method of reducing (or enlarging) drawings by means of two sets of squares, the ratio of their sides corresponding to the scale of the required reduction (or enlargement).

Capt. Deville recommends the perspectometer to be made by first drawing it on paper in a fairly large scale and then making a negative of it, reduced photographically to the desired size of the finished perspectometer. A positive copy of said negative may then be made on a transparency plate, which, if bleached in a solution of bichloride of mercury, will show white lines (they were dark before the bleaching took effect) on clear glass. For the sake of better preservation the perspectometer is varnished when completely dry and hard.

When using the perspectometer to transfer figures from their perspectives to the ground plan, when such figures are

situated in planes perpendicular to the picture plane but inclined against the horizon plane, the center of the perspectometer is placed upon the principal point *P* of the picture plane the same as before, but the perspectometer is now revolved about *P* until the parallel lines of the same are parallel to the trace on the picture plane of the inclined plane (containing the figure to be transferred). In this case the trapezoids of the perspectometer represent the perspective of a net in the inclined plane composed of squares which are now to be projected into the ground plane.

This net of squares in the inclined plane, when projected on the ground plan, will be composed of rectangular figures of equal size, their long sides being in a direction at right angles to the picture trace (or ground line) and of a length equal to that which is intercepted between two adjoining radials of the perspectometer on the trace of the inclined plane (on the picture plane), while the short sides of those rectangles forming the net of the ground plan will be equal to the lengths obtained on the ground line by projecting the points of intersection of the radials of the perspectometer with the inclined plane's trace on the picture plane upon the ground line of the picture plane.

The construction of the rectangular net on the ground plan may now be made in an analogous manner to that mentioned for the squares, and the drawing-in of the figure on the ground plan with reference to its position within the trapezoids of the perspectometer is accomplished in the usual manner.

Should the figure be situated in planes that are inclined to both the picture and the ground planes, then the figure is first projected upon a plane perpendicular to the picture plane and having the same trace in the latter as the inclined plane.

VI. The Perspectograph, Devised by H. Ritter.

Numerous instruments have been devised for the mechanical drawing of perspectives from plans (or from nature), or by means of optical devices, some of which may, inversely, become of use for transcribing perspectives of figures into orthogonal projections, and we have seen that Col. Laussedat as far back as 1849 made his first experimental perspective surveys with the camera lucida or camera clara, devised by Wallaston, which in this case had been improved by Regnault. The perspectograph invented by H. Ritter serves to construct the orthogonal projection of a plane figure from its perspective or to draw the perspective from the plans of the object without referring to the object itself.

Ritter's instrument, manufactured by C. Schroeder & Co. in Frankfort on the Main, has been patented in Germany, Oct. 13, 1883, under No. 29002. It was devised primarily for architectural purposes. For the title of Ritter's descriptive pamphlet, see Literature, paragraph 2, Chapter I.

This instrument in its present form, composed largely of wood, is not well suited for surveying purposes, as it contains too many sources of error, due to lost motion in its bearings; still, its theory being a good one, there is no reason to doubt its ultimate value, even for precise work, if it were carefully made by an expert mechanician, excluding the use of wood and using metal throughout, being guided in its construction by the demands of the utmost attainable precision. Since a carefully constructed instrument based on the present pattern may become useful in plotting the data of a topographic reconnaissance, where, in the nature of the work, rapidity in making the results practically available will often be of greater value than a high degree of accuracy, the following description of this instrument may not be out of place here. For its methods of use in photo-

topographic surveying we respectfully refer to Capt. Deville's work on photographic surveying.

We have seen that the plotted position in the ground plan of a point may be found from its perspective by locating the intersection of the horizontal projection of the ray: "station pictured point" with the line of direction found by revolving this ray with its vertical plane into the ground plane (about the trace of the vertical plane in the ground plane as axis of revolution).

With reference to Fig. 174, Plate XCII,

S may represent the camera station;
M the position of a point plotted on the ground plan GG;
μ its perspective in the vertical picture plane MN;
s the foot of the station S;
XY the ground line of the picture plane MN.

If we draw through the foot of the station a line parallel to the ground line XY and make its length, $s(S)$, equal to sS, join the plotted point M with (S), then it will follow, from the similarity of the triangles $O\mu M$ and sSM, that

$$sS:O\mu=Ms:MO.$$

The triangles $s(S)M$ and $O(\mu)M$ being also similar, we find

$$s(S):O(\mu)=Ms:MO;$$

hence

$$sS:O\mu=s(S):O(\mu).$$

As we had made $sS=s(S)$, the last equation can only prevail if

$$O\mu=O(\mu).$$

To find, therefore, the perspective, μ, of a point, M, given on the ground plan, we first draw through the plotted station, on the ground plan, a line $s(S)$ parallel to the ground line XY, making $s(S)$=height of the station S above the ground plane. Draw the lines sM and $(S)M$, which will intersect the ground line, XY, in O and (μ), Fig. 175, Plate XCIII. On the ground

line $X'Y'$, drawn in another place of the working-sheet, we assume a point O', representing O of the ground plan, and erect $o\mu$ perpendicular to $X'Y'$ in O' and equal to $O(\mu)$, when μ will be the perspective of M in the reverse position of the perspective. The perspective of any other point N on the ground plan may be found in the same way, making $O'Q'=OQ$ and $Q'\nu=Q(\nu)$.

Ritter devised the perspectograph with reference to the preceding relation between the visual ray, SM, Fig. 174, Plate XCII, to a point M, the horizontal projection of the ray, and the plotted position of such point M, the perspectograph performing the preceding construction, Fig. 175, Plate XCIII, mechanically.

The general arrangement of this instrument is shown in Fig. 176, Plate XCIII: sM and $(S)M$ are two slotted wooden arms carrying the tracer, M, at their point of intersection. The connections at s, o, (s), and (μ) are such that the rulers sM and $(S)M$ may slide through these points. The slide connections s and (S) may be moved along the groove or slot of the wooden ruler RT. The sliding piece O is secured to a rod which may slide in the groove shown in the wooden ruler XY, being connected at its other end D with a system of arms, joined together after the manner of a pantograph. The distance OD is maintained unchanged while the instrument is in use.

The center of s is placed over the point which marks the plotted camera station on the ground plan, and the ruler RT is placed parallel to the ground line of the picture plane. s and RT are then secured in this position on the ground plan.

When the arm sM is moved, s being held in a fixed position, the point O will follow the motions of the arm sM, also applying its motion directly to the arm OD (which slides in the groove of XY) and indirectly to the arms of the pantograph system.

The fourth sliding piece (μ) is connected with the point A of the pantograph system by means of a separate piece which insures a permanent distance between (μ) and A while the instrument is in use, and which may slide on the rod OD. The pantograph system is composed of six pieces: four straight arms, AB, AC, $F\mu$,

and $F\mu'$, and two double arms, *CDE* and *BDG*, which are bent at right angles in their points of junction *D*. The sides of the two parallelograms *ABDC* and *DGFE* are all of equal lengths, and the six arms are joined in *A*, *B*, *C*, *D*, *E*, *F*, and *G*. The lengths of the arms $F\mu$ and $F\mu'$ are twice that of the side of the parallelograms. The pencil which describes the perspective may be attached to the free end of either arm $F\mu$ or $F\mu'$.

The angles *GDB* and *EDC* being each equal to 90°, the sum of the two other angles *CDB* and *GDE* must be equal to 180°. The sum of two adjacent angles in a parallelogram being also equal to 180°, it follows that

$$CDB + GDE = CDB + DCA,$$

or

$$GDE = DCA,$$

which shows that the two parallelograms are also equiangular, and as their sides are equal in length it follows that the parallelograms themselves must be equal, but they are placed in different directions. The diagonals *FD* and *GE* of the one are equal to *BC* and *DA* of the other, respectively. The two long arms $F\mu'$ and $F\mu$ being of the same length, $\mu\mu'$ will be parallel to *GE*, both will be perpendicular to the direction of *XY*, and $\mu\mu'$ will pass through *D*. We have, therefore,

$$D\mu' = D\mu = GE = DA.$$

Use of the Perspectograph.—The sliding piece *s* is secured to the working-board over the plotted position of the camera station on the ground plan, still permitting a gliding movement of the arm *sM* in the direction *sM*. The center line of *RT* is brought into a position parallel to the plotted ground line and its position is also secured to the board. The sliding piece (*S*), finally, is moved from *s* (in the groove of *RT*) until *s*(*S*) is equal to the elevation of the station *S* above the ground plane, also securing (*S*) in this position, when it will still permit a gliding

movement of the arm $(S)M$ in the direction of $(S)M$. The center line of the wooden ruler XY is placed upon the ground line (picture trace) on the ground plan.

The manipulation of the instrument and its general working will now readily be understood. For instance, when the tracer M is moved in a direction parallel to RT or XY, the arm sM will also move the slide OD in the same direction. The distance $O(\mu)$ remaining unchanged as long as $s(S)$ undergoes no change, $(\mu)A$ will also remain of a constant length. Hence, AD and also GE as well as $D\mu$ undergo no changes, and the pencil in μ or in μ' will trace a parallel line to XY, representing the perspective of a line of the ground plan (the one traced by M) and parallel to the picture plane.

When M is moved in the direction of sM, away from XY, the positions of O and D remain the same, but $O(\mu)$ will be lengthened, (μ) moves to the right—away from O—carrying the point A with it ($A(\mu)$ being a constant length) and increasing the length of the diagonal DA in proportion to the increase of the length $O(\mu)$. DA, being equal to GE, equal to $D\mu(=D\mu')$, the latter will also be lengthened and μ will move down—away from XY—by the same amount as (μ) is moved to the right. The relation between the construction made in Fig. 175, Plate XCIII, and the mechanical plotting with the perspectograph, Fig. 176, Plate XCIII, will now be evident.

VII. Prof. G. Hauck's Trikolograph and its Use in Iconometric Plotting.

This instrument has been described by Dr. G. Hauck in a memorial commemorating the opening of the new building of the Royal Technical High School at Charlottenburg, near Berlin, Nov. 2, 1884. It serves to reconstruct an object from two perspectives obtained from two different points of view.

The principles which underlie the construction of this instrument hold equally good for the construction of an instrument

which could serve to plot mechanically the ground plan of any object represented on two photographs obtained from different stations.

Prof. F. Schiffner, in 1887, suggested the changes to be made to Dr. Hauck's instrument in order to render it available as an instrument of precision for the use of the phototopographer; still, it seems that mechanical difficulties in its manufacture are yet to be overcome, as the writer has not met with any record of such an instrument having been in use or even constructed.

In Chapter IV it has been shown that a point, A, photographed from two stations, S and S_1, may be plotted in horizontal plan, if the two picture traces gg and g_1g_1, and the two camera stations S and S_1, are given on the horizontal plan, Fig. 177, Plate XCIV.

The two picture planes may be revolved about their ground lines, gg and g_1g_1, into the horizontal or ground plan, when (a) and (a_1) will be the two images of the point, A, revolved into the ground plane. If we draw lines through (a) and (a_1) perpendicular to the corresponding ground lines gg and g_1g_1, then a' and a'_1 (Fig. 177, Plate XCIV) will be the projections of the pictured points a and a_1 into the horizontal plan and the intersection of the radials drawn from S and S_1 to a' and a_1', respectively, will locate the position A' of the point A pictured on the two plates as a and a_1.

This graphical determination of the plotted position A' of the point A may be accomplished mechanically by placing slotted rulers with their center lines upon gg and g_1g_1 Fig. 178, Plate XCIV, and indicating the directions of the perpendiculars, dropped from the pictured points (revolved into horizontal plan) upon the ground lines, by two arms, $(a)bc$ and $a'b$, of a panto. graph combination, where

$$(a)b = bc = a'b.$$

The points $(a)a'$ and c will always be situated on the periphery of a semicircle described about b as the center, and as

the points c and a' are permanently held on the line gg, the angle $aa'c$ (angle of the periphery subtending the semicircle) will be equal to 90° for all inclinations that may be given $(a)c$ against gg.

The directions of the radials Sa' are laid down mechanically by means of two slotted rulers Sa' and S_1a_1', held in position by the studs in S and a' (in S_1 and a_1'), both rulers being revolvable about the fixed points S and S_1.

This instrument, of which the characteristic features are shown in Fig. 178, Plate XCIV, performs the constructions mechanically which were made graphically or geometrically in Fig. 177, Plate XCIV.

The slotted rulers gg and g_1g_1 are secured to the plotting-board (with their center lines on the picture traces) by means of thumb-tacks T. The pantograph-arms $(a)c(a_1)c_1$ and $a'b$ $a_1'b_1$ are connected with these rulers by means of sliding joints c (and c_1) and a' (and a_1'), while the studs which mark the stations S and S_1 end in cylindrical projections which fit into the slots of the rulers Sa' and S_1a_1', the latter fitting also over similar cylindrical attachments to a' and a_1', in such a way that the rulers Sa' and S_1a_1' may freely glide over the points S and a' (or S_1 and a_1'), and at the same time may revolve about the fixed points S and S_1 respectively.

The points (a) and (a_1) are provided with tracers and a pencil-slide is attached to the intersection of the rulers Sa' and S_1a_1' (in A') in such a way that the pencil point may freely slide either way in the grooves of Sa' and S_1a_1'.

A comparison between Figs. 177 and 178, Plate XCIV, will plainly show that A' will always represent the plotted position of two images (a) and (a_1) (revolved into horizontal plan) of the identical point A.

It may not always be possible to identify both images of the same point A on the two pictures, and in order to apply Prof. Hauck's method, to identify the second image (on the second photograph) by means of the so-called "kernel points" the instrument, shown in Fig. 178, Plate XCIV, must be modified

in such a way that the point of the second tracer will always be upon the image (on the second picture) which the point of the first tracer designates on the first picture (revolved into the ground plane).

We had seen in Chapter IV that the line connecting the image of any point A on the first picture with the image of the second station (kernel point (s_1), Fig. 179, Plate XCV) and the line connecting the image of the same point A on the se ond picture with the image of the first station (kernel point (s), Fig. 179, Plate XCV) will bisect the same point σ of the line of intersection of the two picture planes. The picture planes being vertical, this line of intersection will be the vertical line passing through the point Ω of the ground plane (point of intersection of the two picture traces or ground lines gg and g_1g_1). The picture planes having been revolved about their ground lines as axes into the horizontal plan, this line of intersection $\sigma\Omega$, also revolved into the ground plane (and about gg and again about g_1g_1), will appear twice, once as $\Omega(\sigma)$, perpendicular to gg in Ω, and again as $\Omega(\sigma_1)$, perpendicular to g_1g_1 in Ω. As the points (σ) and (σ_1) represent the same point σ, revolved into the horizontal plane, once about gg and again about g_1g_1 as axes, the lengths $(\sigma)\Omega$ and $(\sigma_1)\Omega$ must be equal.

In order, therefore, that this instrument (Fig. 178, Plate XCIV) may work in harmony with the principles which underlie Prof. Hauck's method, it will have to be modified to fulfill the following conditions:

A line drawn through the kernel point s_1 and any point pictured on the first photograph, and a line drawn through the kernel point s and the image on the second photograph of the same point, are to intersect the line of intersection of both picture planes in the same point σ, or, the two lines revolved into the horizontal plan (with the picture planes) must bisect the revolved lines $(\sigma)\Omega$ and $(\sigma_1)\Omega$ in points (σ) and (σ_1), which are equidistant from Ω.

The complete instrument is represented in a general way

in Fig. 179, Plate XCV. The two slotted rulers gg and g_1g_1, of Fig. 178, Plate XCIV, have been supplied with additional arms $\Omega(\sigma)$ and $\Omega(\sigma_1)$, each arm including an angle of 90° with its ruler. These rectangular elbow-pieces are secured to the plotting-board by four thumb-tacks T after the rulers $g\Omega$ and $g_1\Omega$ had been placed with their center lines upon the picture traces gg and g_1g_1, respectively, in such a way that the intersections of the center lines of the elbow-rulers, at the rectangular elbow end of the rulers, coincide with the intersection Ω of the ground lines or picture traces gg and g_1g_1. The pantograph-arms, representing the ground lines of the pictures, are attached to the rulers the same as in Fig. 178, Plate XCIV. Studs are inserted into the kernel points (s_1) and (s), and the arms $\Omega(\sigma)$ and $\Omega(\sigma_1)$ support a ruler $(\sigma)(\sigma_1)$, which may glide freely over these arms of the elbow-pieces. To cut off equal lengths on the elbow-arms $\Omega(\sigma)$ and $\Omega(\sigma_1)$ by this ruler $(\sigma)(\sigma_1)$ the angle $d(\sigma)e$ is adjustable, and it should be regulated for each set of two picture traces to make

$$(\sigma)\Omega=(\sigma_1)\Omega.$$

When $(\sigma)d$ is moved along the slot of $(\sigma)\Omega$ the slide point (σ_1) will move along $(\sigma_1)\Omega$, $\Omega(\sigma)$ always being equal to $\Omega(\sigma_1)$. The screw d serves to clamp the angle $d(\sigma)e$ for any opening corresponding to the angle $g\Omega g_1$ included between the picture traces. Slotted rulers are now placed over the studs marking the kernel points (s_1) and (s), the slots also receiving the cylindrical prolongations of the tracers (a) and (a_1) and those of the slide points (σ) and (σ_1) respectively. Finally two slotted rulers RS and R_1S_1 are placed over the studs S and S_1 (they mark the plotted positions of the two stations) and over the sliding joints a' and a_1' (which are the same as those in Fig. 178, Plate XCIV). At their point of intersection, A', the sliding pencil point is inserted into the slots, and this completes the instrument. If we now move the tracer (a) on the first photograph, the pantograph arms $(a)c$ and ba' will change the position

of the ruler SR into the direction of the radial from S to the horizontal projection—on the picture trace—of the pictured point designated by the tracer point (a) on the first photograph and the ruler $(a)(s)$ is moved, locating the point (σ). This change in the position of (σ) produces a corresponding change in the sliding point (σ_1), which in turn changes the position of the tracer (a_1), causing the pantograph-arms $(a_1)c$ and b_1a_1' to move, and a change in the position of a_1' will cause the radial ruler R_1S_1 to assume a new position also and the intersection of RS with the new position of R_1S_1 locates the plotted position in horizontal plan of the point under the tracer on the first photograph without actually having identified the corresponding image as the identical point under the tracer (a_1) on the second picture.

If a line on either photograph is followed out by one of the tracers (a) or (a_1), the pencil point A' will draw the horizontal projection of the pictured line, the second tracer being watched merely for the sake of obtaining a check or to aid its course, if necessary, by a gentle tapping, when the movements of the various parts of this instrument should retard its motion owing to too much friction or lost motion.

Until now no perfect perspectograph has been constructed, and no matter how accurately such instruments—like the one just described—may be made by the mechanician, there will always remain some unavoidable imperfections in the material or in the workmanship of the instrument, producing more or less error in the results. For accurate and precise work, therefore, all iconometric plotting (when applying the radial or so-called plane-table method) should be accomplished with the aid of graphical or geometrical constructions, at least for all control points of the survey, relegating the use of perspective instruments to the filling in of such details, which in an instrumental survey of like character would be sketched by the topographer.

VIII. The Carl Zeiss Stereoscopic Telemeter and the Stereocomparator, including the Stereophotogrammetric Surveying Method, Devised by Dr. C. Pulfrich.

Stereoscopic surveying, when employed for phototopography, has many advantages, especially if the stereoscopic views of the terrene may be transferred into the orthogonal horizontal projection of the plan or map by means of stereoplanigraphs, or stereoscopes that are supplied with the necessary details and means for adjustment that may be required for the semi-mechanical plotting of topographic control points.

The idea of using two stereoscopic views of the ground, obtained from two properly selected stations, in a specially devised stereoscope and projecting the selected characteristic terrene points of the stereoscopic image directly on the plotting-sheet, by means of a movable projecting index mark, occurred to Capt. Deville about ten years ago. Owing to the pressure of other official duties, however, Capt. Deville had to suspend the continuance of his experiments in this direction. This interruption is greatly to be regretted, as he had practically solved the problem of stereoscopic plotting by using a modification of the Wheatstone stereoscope. A description of Capt. Deville's interesting instrument may be found in:

Transactions of the Royal Society of Canada, Second Series, 1902-1903, Vol. VIII, Section III, "On the Use of the Wheatstone Stereoscope in Photographic Surveying." E. Deville.

Also in

A. Laussedat. "Recherches sur les Instruments, les Méthodes et le Dessin topographiques." Tome II. Paris, 1903. "La Stéréoscopie appliquée à la Construction des Plans."

Dr. C. Pulfrich. "Ueber eine neue Art der Herstellung topographischer Karten und ueber einen hierfuer bestimmten Stereoplanigraphen." Zeitschrift fuer Instrumentenkunde, Heft V (Mai), 1903, XXIII Jahrg.

Dr. Pulfrich has devised a stereoplanigraph which is being made by the Carl Zeiss firm in Jena, a description of which may be found in the last-mentioned paper by Dr. Pulfrich. This instrument seems to be planned on the lines suggested by Capt. Deville.

A perfected stereoplanigraph would be the ideal instrument for the rapid plotting of topographic features and details if the terrene is controlled by a close network of triangulation.

A. The Stereoscopic Telemeter, or Range-finder.

The stereoscopic telemeter, or aerial distance measure, manufactured by the Carl Zeiss Optical Works in Jena, Germany, was first brought to general notice in a lecture delivered by Dr. C. Pulfrich before the Society for Natural Research, Munich (Sept. 19, 1899).

This telemeter, devised by Dr. Pulfrich, is the outgrowth of ideas that had been suggested in a measure by Prof. Porro to break the straight course of the light-rays in a telescope, by means of a series of prisms, into a zigzag path and thus reduce the length of the ordinary telescope.

The Carl Zeiss Optical firm not only succeeded to improve on the quality of the prism telescopes heretofore in use, but it succeeded also to combine two such telescopes into a binocular set. The relief effect produced by the Zeiss prism binoculars, based on the difference between the two retinal images, is accentuated by an optical increase of the interocular distance, simply by setting the two objectives of the binoculars farther apart. The ratio between the ocular and the objective distance gives the "stereoscopic power" of these stereobinoculars.

The great practical success of this combination, however, is mainly due to the recent discoveries made in the optically worked glass compositions produced by the now world-famed Jena Optical Glass Works. Dr. Pulfrich could now realize H. Grousillier's idea of the aerial distance scale, and aided by

the excellence of the mechanical equipment of the Carl Zeiss firm, the present form of the "stereotelemeter" has been manufactured and placed on the market.

With this portable stereoscopic telemeter distances may be read off directly, the degree of accuracy attainable in the measures being almost entirely independent of the shapes of the objects determined, which, furthermore, may be stationary or in motion. A special transverse scale is also provided for measuring the width or length and the height of any distant object, for making measurements in "frontal planes."

The Carl Zeiss firm has placed three distinct types or grades of stereotelemeters on the market, differing in range, magnification, and weight, and, of course, also in price.

The so-called "total relief effect" may be expressed by the product $\frac{E \times G}{e}$,

where E=distance between objectives (=510 mm.);
e=distance between eyepieces (= 65 mm.);
G=magnification (= 8.).

The middle-size telemeter, to which the figures just given refer, will have a total relief effect of 63. That is to say, if differences in relief on the single plate are not observable beyond 450 meters, the stereoscopic image, as it appears to the observer through this stereotelemeter, will show differences in depth or relief at 63×450 m.$=28.3$ km. This, however, does not mean that any such distances may be read with its aerial distance scale; it simply gives the extreme limit for recognizing terrene forms, all points beyond that distance appearing as infinitely far off.

If we direct the stereotelemeter to a point P at infinite distance (Plate CIX) the component images of the point P will be at p and p'. If we now consider a second point P', just in front of P, its image will still coincide with p in the left image plane, but in the image plane of the right binocular tube it will appear at p'', to one side of p'.

The distance $p'p''$, spoken of as the linear parallax of the two points P and P', is directly proportional to the distance between the two points. The rays $o'p'$ and $o'p''$ include the angle of parallax $=\delta$, and as the triangles $o'p'p''$ and $P'OO'$ are similar we will have the proportion

$$p'p'':f=E:D,$$

where f = focal length of o;

E = interobjective distance, or telemeter base;

D = distance of point P from O, PP' being negligible in comparison with OP.

Hence the linear parallax

$$a=p'p''=\frac{E\times f}{D}.$$

E and f being constants, we find by differentiation

$$dD=-\frac{D}{a}da,$$

and substituting the above value for a we find

$$dD=-\frac{D^2}{Exf}da.$$

The error in linear parallax, da, is directly proportional to the product of the focal length and the angular parallax δ, and inversely proportional to the magnification G.

$$da=\frac{f\times\delta}{G},\quad f=\frac{G\times da}{\delta},$$

and we may now write

$$dD=-\frac{D^2}{E\times G}\delta.$$

If we now designate by r the range of stereoscopic vision by unaided eyes—in other words, if r is that distance at which an object must be placed to be seen under an angle of parallax $=\delta$ —we will have the relation

$$\delta=\frac{e}{r}.$$

As δ will always be a small angle we can substitute the tangent for the angle.

If we designate by R the range of the field that is controlled by the total effect of relief, we will have

$$R=r\times\frac{E}{e}\times G=\frac{E\times G}{\delta}.$$

After substitution of this value in the above equation for dD we finally find

$$dD=\frac{D^2}{R}.$$

Numerous experiments have shown that the angular parallax (δ), the angle under which objects situated in different but very distant frontal planes cease to appear to be at different depths when examined under binocular vision, amounts to 30 seconds for normal eyes (Helmholtz gives $\delta=1''$).

Hence we find from

$$e=r\cdot\delta=r\times 30''.$$

For small angles we can substitute for one second the value 1:206265; hence for an interocular distance of 65 mm.,

$$0.065=\frac{r30}{206265}, \quad \text{or} \quad r=\frac{0.065}{30}206265;$$

$r=446.9$ m., or in round numbers, 450 m.

The "*hunting*" or "*sporting*" *telemeter* has a base of 32 cm., a telescopic magnification of 4, and a scale for reading distances from 20 to 500 meters. Objects beyond 8000 meters appear as infinitely far off. The weight of this instrument is about 2½ kgr. Fig. 1, Plate CVIII, shows a general view of the Zeiss sporting-telemeter.

The "*infantry telemeter*" has a 51-cm. base, a telescopic magnification of 8, and a scale for distance reading from 90 to 3000 meters. Objects beyond 28 km. appear at infinite distance. This instrument has a weight of about 3½ kg., and it cannot well be manipulated without a support. The telemeter with suitable (tubular) stand weighs 6½ to 9½ kg.

The so-called "*stand telemeters*" (the central part of one is shown in Fig. 2, Plate CVIII) have a 1.44-m. base, a telescopic magnification of 23, and a scale for reading distances ranging from 500 to 8000 meters. Objects beyond 230 km. appear at infinite distance. These stereotelemeters require a rigid support, and the Zeiss firm has devised a special tripod for them. The weight without tripod is 15½ kg. The packing-case weighs 20⅓ kg. The tripod with fork-rest and tilting joint weighs 18½ kg.

The attachment marked *B* in Fig. 2, Plate CVIII, is to be secured to the right eyepiece for illuminating the image planes in the binocular microscope of the stand telemeter when adjusting the ocular scale in the stereoscopic image plane. It is used in connection with a pair of Gautier-Prandl prisms that may be adjusted over the objectives, as indicated by dotted lines in the diagram, Plate CIX. When these Gautier-Prandl and the eyepiece prisms are in the position shown, the light-rays entering o' through the prism *B* will pass from m' to O', thence through the right Gautier-Prandl prism, through the left prism, through O and m, emerging through o, illuminating both image planes in their course, as indicated by the dotted line, Plate CIX.

We will not refer here to the adjustments nor to detailed directions for using the different types of stereotelemeters, as printed directions are sent out with every instrument.

The errors affecting the readings of these telemeters increase with the square of the distance. There is a certain zone of uncertainty for all points in a frontal plane. That is to say, that for a certain reading made with the well-adjusted telemeter the distance, as read off on the aerial scale, may be too long or too short by a certain amount; each reading will be affected by a positive or a negative error.

In the table opposite the probable errors,

$$dD = \frac{D^2}{R},$$

affecting different distances, read with the three types of telemeters, have been tabulated for comparison.

To use a stereoscopic telemeter successfully the observer must be able to see "stereoscopically"; this, of course, excludes all persons with defective vision or who have developed the power of vision in one eye at the expense of the other, or whose eyes are abnormally spaced, less than 58 or more than 72 mm. apart. Both eyes should be used simultaneously, and it will require quite a little practice before the observer will become expert in distinguishing differences in the distance between objects apparently close together in the stereoscopic field and yet in different frontal planes.

To test an observer's ability to see stereoscopically, Dr. Pulfrich has constructed a stereoscopic "test-plate" ("Pruefungstafel fuer stereoskopisches Sehen"), which is issued together with his treatise, "Ueber eine Pruefungstafel fuer stereoskopisches Sehen," published in the Zeitschrift fuer instrumentenkunde, Heft 9, 1901. The figures and diagrams shown in that test-plate not only give the means for a quantitative test but they are also designed for making a qualitative test of the observer's stereoscopic vision.

Plates CII and CIII show roughly made diagrams for testing stereoscopic vision in the quantitative sense only. The

Distance = D in Meters.	Probable Error in Meters for the		
	Sporting Telemeter: Base = 32 cm., Magnification 4.	Infantry Telemeter: Base = 51 cm., Magnification 8.	Stand Telemeter: Base = 1.44 m., Magnification 23.
20	0.05	—	—
30	0.11	—	—
40	0.20	—	—
50	0.31	—	—
75	0.70	—	—
90	—	0.3	—
100	1.25	0.3	—
125	—	0.5	—
150	2.8	0.8	—
175	—	1.1	—
200	5.0	1.4	—
300	11.3	3.2	—
400	20.0	6	—
500	31.3	9	2.5
600		13	2.8
700		17	3.6
750		—	4.4
800	Objects beyond 8 km. appear as at infinite distance	23	6.7
900		29	9.9
1000		35	13
1250		55	18
1500		80	22
1750		109	27
2000		140	33
2250		181	39
2500		223	54
2750		270	70
3000		320	110
3500			156
4000			215
5000		Objects beyond 28 km. appear as at infinite distance	278
6000			352
7000			440
8000			
9000			
10000			
			Objects beyond 230 km. appear as infinite

circles, Plate CII, are numbered with their increase in distance, No. 1 being nearest and No. 9 farthest. In Plate CIII the pyramid is nearest the eyes; then follow the cross, concentric rings, circle near the cross, large ring or circle (inclosing the figures), central wheel with four spokes, cube, smaller circle (below the

cube), base of large cone, and finally the base of the small cone. The axes of the two cones are not in line and the base of the pyramid is not in a plane parallel with the large circle, its left corner being tilted up a little. The Maltese cross, too, has its upper two arms tilted forward toward the observer, the end of the left upper arm being somewhat nearer than the upper end of the right arm. A careful examination of these plates will show whether the observer can see stereoscopically.

In looking into the stereotelemeter the aerial distance scale should appear free in space, in a plane slightly raised toward the distant end of the scale. As soon as the particular part of the scale has been determined, by inspection, which coincides with the object, the distance of the latter is obtained within a certain margin of limitation, as already referred to in the preceding paragraphs.

The more expert the observer, the smaller the limit of differentiation will be, although there will always remain a certain margin of uncertainty corresponding to the limit of power of the stereoscopic definition, as noted in the table previously cited.

To become efficient in the rapid use of the stereotelemeter, it is essential that the observer make himself thoroughly familiar with the divisions of the aerial scale of his instrument. It should be noted that the subdivisions of the scale apparently grow smaller with increasing distance, and the observer should not only be able to read off each actual scale mark quickly and correctly, but he should also be trained to estimate fractions of the subdivisional scale lengths accurately. (Attention may be called to the fact that the nearest half-reading between two successive scale marks falls a little beyond the space center, the quarter a little beyond the geometrical quarter-space, etc.)

Plate CI represents the measuring-scale used in the Carl Zeiss hunting stereotelemeter. The marks of this scale are arranged in four sections, the scale appearing as a zigzag line. The first section, from 20 to 25 m., apparently appears in front

of the diaphragm or circle which incloses the scale. The four sections control distances as follows:

(1) 20 to 25 m., divided into 1-meter spaces;
(2) 25 to 50 m., divided into 1-meter spaces;
(3) 50 to 70 m., divided into 2, and 70 to 100 m., into 5 m. spaces;
(4) 100 to 160 m., in 10, 160 to 300 m., in 20, and 300 to 500 m., divided into 50 m. spaces.

The reproduction of this scale on Plate CI is faulty; inasmuch as the triangular division marks 4 and 6, representing the 40 and 60 m. divisions of the scale, are considerably out of line, some of the other marks show similar imperfections, but less marked than these two.

The glass plate having the aerial distance scale etched into its surface is also provided with a transverse scale (divided into twenty equal parts, Plate CI) for measuring widths and heights of objects. In the stereoscopic fields of the telemeters both scales stand out very clear and distinct, being photographic reductions of the large-scale originals.

For the first practice work with the stereotelemeter, well-defined objects, preferably those that are silhouetted against the sky, should be selected. The instrument is first directed toward the sky, the interocular distance adjusted, and the eye-pieces focused. The instrument is now gently revolved downward until the object ranged upon appears in the lower field, when the aerial scale should appear free in space above the object. It will now remain for the observer to find that place of the scale which coincides with the object (which will be in the same frontal plane with it) to estimate the fractional distance from nearest scale mark to object.

The scale divisions are indicated by small triangles, the acute angle pointing downward, and to determine the position of an object with reference to the scale, the highest point of the object

is brought as close as possible to the imaginary line, connecting the scale marks near the object, when the mark to the near side of the observer and close to the object is picked out, the observer estimating the distance of the object beyond this mark to arrive at the actual distance. Should the mark just beyond the object be observed, instead the nearer one as just stated, the tendency generally seems to be towards overestimating the distance.

The Carl Zeiss firm has also constructed a stereoscopic telemeter without an aerial scale. The stereoscopic field of this telemeter shows an index mark which is movable by the aid of a micrometer screw. With this instrument several independent measurements of the distance between two objects may be made, similar in manner to the method of repetitions.

The Carl Zeiss stand stereotelemeter may be used at night for estimating or measuring the distances of lights (vessels, lighthouses, etc.), by illuminating the scale on the diaphragm plate, means for doing this being provided if a suitable lantern be at hand.

The binocular microscope of the stereocomparator, of which a description follows, is built after the model of the stereotelemeter, its telescope with prisms being here replaced by a binocular microscope with reflecting mirrors, through which the upright stereoscopic images are examined under enlargement.

B. The Stereocomparator and the Stereophotographic Surveying Method.

The angle included at a distant point between the visual rays from the eyes of the observer is known as the parallactic angle, or parallax. The parallax increases when the point approaches the observer and *vice versa*. For a point at infinite distance the two visual rays will be parallel; the parallax will be $=0$.

The estimation of the distance of a point, when observed with both eyes, depends largely upon the subconscious gauging, or mental measurement of the parallax. The distance of

an object when viewed with one eye only may still be estimated, but in monocular vision such estimates must be based mainly upon the degree of diminution in the apparent size of the object if a familiar one, or the reduction in size of closely neighboring bodies of which the actual sizes are known; for instance, a person or an animal that may be standing near the distant object.

The stereophotogrammetric method is based on measurements made simultaneously on two stereoscopic pictures showing the same terrene and exposed from all the ends of a comparatively short base line. These simultaneous measurements, on corresponding plate pairs, of the coordinates to locate identical terrene points with reference to the horizon and principal lines are made with the "stereocomparator," ingeniously devised by Dr. C. Pulfrich, a member of the scientific staff of the Carl Zeiss Optical Works in Jena.

The principle underlying the construction of the stereocomparator may be elucidated in the following manner, suggested by P. Seliger of the Prussian Topographic Bureau. Two pointers, made of black wire of equal thickness and of equal lengths, when suspended over the face of two stereoscopic views secured in a stereoscope will become superimposed and appear as a single wire in the stereoscopic image of the two views.

If we now move one wire over the face of the picture, bringing it a little closer to the wire over the other picture (we reduce the parallax), the apparent position of the wire index in the stereoscopic image will have become more distant, and as soon as the distance between the two wires is made to coincide with the interocular distance the superimposed images of the wires will appear infinitely far off in the stereoscopic field. By thus changing the relative positions of the two wires, the observer can transfer their stereoscopic image to any point of the stereoscopic field.

All points of the stereoscopic image that are in a vertical plane parallel to the stereoscopic base have the same vertical distance from the base line. Since the vertical distance of such frontal

plane has the same ratio to the base length as the focal length of the camera has to the parallax, we can compute such distance if we know the parallax, the base and the focal length being constant for every stereoscopic picture pair.

The stereoscopic picture pairs are placed on the stereocomparator to be measured through a binocular microscope similar in construction as the Zeiss "stereoscopic telemeter," by means of which the two coordinates and the parallax of any pictured point may be measured, after optical bisection, by reading the corresponding verniers of the three scales that are connected with the stereocomparator. The data thus obtained suffice for the cartographic location of the point in both the horizontal and vertical sense.

Referring to Plate CIV, which shows the general arrangement of the stereocomparator, we designate by

*P*1 and *P*2 the left and the right pictures;
H the rack-and-pinion motion for moving both pictures together from left to right and *vice versa;*
M′ a screw for moving the right picture alone and in the same sense as the motion imparted by *H*;
M a screw for turning the right picture;
N a screw for raising or lowering the right picture;
T the turntable for the right picture;
S a screw for moving the left picture independently from right to left and *vice versa;*
R and *h* plates running in grooves, to be raised, lowered, or moved transversely;
A and *B* scales for measuring the coordinates of points pictured on both plates;
a scale for measuring the parallax of pictured points;
C binocular microscope; it may be raised or lowered by turning the screw *V*, the amount of such change in altitude to be read off within 0.1 mm. on the vernier of scale *B*.

To be viewed stereoscopically the two pictures *P*1 and *P*2

are placed on their plates, *R* and *T*, in a position corresponding to that they had when the exposure was made, with their principal lines made parallel and vertical. If the base-line ends are not of the same elevation, the right plate is raised or lowered until corresponding points appear equally high when examined through the binocular microscope.

The binocular microscope may be moved toward or away from the negatives by turning *E* and each eyepiece is independently adjustable to the eyes of the observer. The objectives also are movable in the direction of the optical axes, to give a range of magnification of 4 to 8 diameters. Two index marks have been provided, one in each image plane of the microscopes, for bisecting identical terrene points. By turning the micrometer screw *F* the index of the right microscope may be moved, changing the apparent distance of its stereoscopic image. For one turn of the micrometer *F* the index will be moved 0.2 mm., which would correspond with a change of the right plate of 0.3, 0.2, and 0.15 mm., using a magnification of 4, 6, and 8, respectively.

To find the parallax of a pictured point the stereoscopic image of the index mark is set at apparent infinite distance and both plates are now moved and adjusted until the terrene point to be measured coincides with this index mark. The motion of the right plate, accomplished by turning the screw *M′*, to bring the mark and point into contact, is read off on the vernier *a*, which reads to 0.02 mm. By estimation, however, the value for the parallax may be obtained within 0.01 mm. After the index has been made to bisect the point the readings of the verniers *A* and *B* will give the coordinates of the pictured point with reference to the left picture (left base station).

The main advantage claimed for the use of the stereocomparator in phototopography rests in the fact that *one* pointing of the index on the point at once gives the elements for the cartographic location of the point, whereas with the plane-table or radial method three distinct measurements would have to be

made before the pictured point may be plotted, involving the separate measures of two abscissæ and one ordinate. With the stereocomparator the coordinates are measured directly on the negatives with microscopes and verniers, and the accuracy obtained should be greater than obtainable with the plane-table or radial method, using paper prints, dividers, and scales.

The index mark being placed upon each terrene point that is to be plotted from the pairs of pictures, it is evident that the better the definition of such points the closer will be their subsequent cartographic location.

The three readings made on the scales A, B, and a give the data for locating any pictured point (bisected with the movable index mark) in regard to direction, distance, and elevation, and with reference to the left station.

The abscissa x (Plate CV, Fig. 1), read off on scale A, is plotted in the usual manner by laying off the distance on the picture trace T from the principal point O, a line SR, drawn through the end of x from the left station S gives the line of direction to the bisected point P.

The distance is ascertained from the vernier reading of scale a which gives the linear parallax of the bisected point. The distance may be computed from the equation

$$A : B = f : a,$$

$$A = \frac{B \cdot f}{a},$$

where B is the distance between the two stations,
f the constant focal length of the camera, and
a the parallax as read off on the scale.

In Fig. 1, Plate CV, TT represents the picture trace, x the abscissa of the point P, the plotted position of which will be on the radial SR. The value for A, as computed above, is laid off on the principal line from S. A parallel

to TT, drawn through the end of A, will bisect SR in P, which is the horizontal projection of the bisected point.

Dr. Pulfrich recommends a graphical solution of the equation

$$A=\frac{B\cdot f}{a},$$

of which the product $B\cdot f$ is a constant for every pair of pictures. Referring to Fig. 2, Plate CV,

$SS_1=B=$ base line;
$TT=$ picture trace of left picture;
$a=$ vernier reading for parallax, laid off on TT from O.

If we now draw the radial Sr, the intersection of the latter with S_1b, drawn parallel with SO, will cut off the distance A on S_1b, and the point to be plotted will be on the line MN, drawn parallel to TT at the distance A from S. The plotted position may now readily be found by laying off the abscissa x from O and drawing the radial SR; the intersection of the latter with MN locates the plotted position of the point P.

Fig. 3, Plate CV, shows the simple device suggested by Dr. Pulfrich for the graphical solution of the equation for A. A drawing-board is covered with a tough paper and a line SO is drawn parallel with its lower edge. On SO, at a distance 1.5 f. from S, a vertical UT is erected and a scale of divisional parts equal to 1.5 mm. is laid off on UT. The line SO is provided with a 1000-meter graduation in the plotting-scale (say 1:25000). LL is a straight edge secured to the board parallel with SO. G is a transparent film of celluloid attached to a brass strip k in such a way that it may readily be slid along LL over SO. This transparent plate G has two graduation, tt and t', in the reduced scale of the map. The ruler SR, also provided with the reduced scale of the map (1:25000), may be revolved about the pin in S.

To use this device the base line for a pair of plates is laid

off on tt, say in tenfold scale of the map. After the parallax a has been read off on the scale of the stereocomparator, the ruler SR is placed on UT to cut off the length $10a$, and G is moved until the base end, marked off on tt, coincides with the fiducial edge of SR. The corresponding value for A may now be read off on SO, using the scale t' for the subdivisional parts of SO.

To find the distance SP of the plotted point from the left station S, the position of G is maintained unchanged, while the edge of SR is made to coincide with that division mark of the scale UT which corresponds with the abscissa x of the pictured point. The distance SP may now be read off on SR to be transferred to the radial SR, Fig. 1, Plate CV.

The difference in elevation of pictured-point and left-base station,

$$h=\frac{A\cdot y}{f},$$

may also be found graphically. After the distance SP has been read off, G is held in the same position and SR is brought to coincide with that scale division on UT which corresponds with the ordinate (read off on scale B of the stereocomparator), when the reading of the scale tt, between SO and SR, will give the value for h in meters. Instead of moving SR to bisect the end of the ordinate y on UT it is desirable to use a multiple part of y, say $10y$, and divide the final reading by 10. The elevation of the plotted point is now derived from the elevation of the left station in the customary manner, referring h to the elevation of the horizon line of the instrument at the station and allowing for curvature and refraction for points over 2000 m. distant from S.

The apparent length of the index mark in the stereoscopic image plane of course corresponds to different heights, according to the distance of the bisected object; the relation between

both, however, may readily be ascertained when the actual or absolute length of the index mark be known. This length is best found by bringing the upper end of the mark into contact with a well-defined horizontal line in the picture and noting the reading of the scale of ordinates (scale B), then bringing the lower end of the mark into contact with the same horizontal line and again noting the vernier reading of the scale B. The difference between the two readings will equal the absolute length of the index mark ($=m$).

The comparative length value$=M$ of the index mark for a distance$=A$ may be computed from the formula

$$M=\frac{m}{f}\cdot A.$$

If the value for m be found 0.75 mm. and the constant focal length of the camera be 250 mm. the value for M would be 0.003 A. Now, say the lower end of the index mark coincides with the base of an embankment at an apparent distance from $S=A=4000$ m., while the crown of the embankment may bisect the iudex line at one third of its length, the absolute height of the embankment would then be

$$\frac{4000\times 0.003}{3}=4 \text{ m.}$$

It is very essential that each pair of plates be exposed in a vertical plane containing the base line or being parallel with it. If such be the case, points lying at infinite distance in the vertical planes of the objectives should appear pictured in the principal lines of the plates. If either of the plates, say P, includes an angle$=\delta$ with the vertical plane of the other, the distant point will be pictured to one side of the principal line (see Fig. 1, Plate CVI). The distant point A will be pictured at a_1 in plate p_{11}, but the principal point will be to one side, at a_{11}.

The plates after being placed on the holders ot the stereocomparator are adjusted by means of the horizon and principal lines, and in this case all parallax values will be measured too small by

$$v=f\cdot\delta.$$

A correct measurement of the length of the base in rough mountain regions often offers serious difficulties, telemeter readings generally being the only available means for measuring these base lines. Any error made in the base will affect all distances determined from its left station, and such being the case it would appear advisable to select relatively long base lines. The lengths of the latter, however, are controlled by the fact that picture pairs can no longer be viewed stereoscopically in their full extent when the length of the base exceeds a certain limit. Pictures obtained from the ends of too long a base will have but limited distance zones that may be examined stereoscopically through the binocular microscopes; areas outside of these, both near and far, will appear blurred and indistinct. The examination of such plates through the microscopes is not only very trying to the eyes, but the observer also loses the general view of the terrene and he will have to refocus the microscopes for every change in distance.

For a constant focal length of 241.5 mm. and an error in parallax of 0.01 mm., errors in distances may be made, for base lengths of 50, 100, 200, and 300 meters, as listed in the following table:

Distance of Bisected Point in Meters.	Length of Base Line in Meters.			
	50 m.	100 m.	200 m.	300 m.
1000	0.8	0.4	0.2	0.1
2000	3.3	1.7	0.8	0.5
3000	7.4	3.7	1.9	1.2
4000	13.2	6.6	3.3	2.2
5000	20.7	10.3	5.2	3.4
7500	46.8	23.4	11.7	7.7
10000	82.8	41.4	20.7	13.8

If errors in position of ± 15 m. be permissible in rough mountain work plotted in 1:25000 scale, a mean error of ± 3 m. may be accepted for the same kind of work plotted in 1:10000 scale.

For a parallax error not exceeding ± 0.01 mm. distances to 6000 meters from the base stations should be controlled, and for the 1:25000 plotting-scale base lines of 100 meters preferably should be selected. For the 1:10000 scale a 100-meter base should be selected for distances up to 3000 meters and a 200-meter base for 4000 meters, etc. If the objective has a focal length shorter than 240 mm. the base should be made proportionately longer. For instance, for a focal length of 180 mm. the base lines as given above should be increased by one quarter.

The terrene pictured on a pair of stereoscopic plates, when examined through the binocular microscopes, appears very much like a relief model of the country, the changes in the surface formation being far more clearly shown than in the landscape itself when viewed from either of the two base stations.

For the best iconometric results each plate should contain from 6 to 12 control points of known elevations and positions (tertiary triangulation points). After the left base station and all the control points have been plotted, the two stereoscopic plates are placed on the comparator frame to be adjusted in the manner already described. After the parallaxes, abscissæ, and ordinates of all the control points that are pictured on the plates have been measured and tabulated, the picture trace of the left picture is plotted, based on the computation of the radials drawn to two control points. It is preferable to select two extra axial points, one near the left and one near the right margin of the plate, for plotting the picture trace. The position of the latter is checked by means of the abscissæ of the other pictured control points. It would not be sufficiently accurate for our purpose ("stereophotogrammetry") to plot the picture trace by means of a paper strip, as generally used in the plane-table or intersection method.

Parallel with the picture trace and from $1\frac{1}{2}$ to 2 times its

distance from the station point a scale is drawn having the same graduation and numbering as the scale (of abscissæ) A of the comparator, the divisional parts of course being enlarged, according to the selected distance, $1\frac{1}{2}$ to 2 times. A ruler having the plotting-scale along its fiducial edge may be secured to the station point in such manner as to revolve about the station with the zero mark of the scale as pivot. With these means the pictured points may be quickly plotted without actually drawing their lines of direction, which radiate from the station.

The next step is to check the position of the horizon line by means of the ordinates of the pictured control points. Any correction affecting all points alike is made by changing the zero mark of the scale B on the comparator. If the horizon line has to be raised or lowered on one side, the plate will have to be turned correspondingly on the holder of the comparator. In the latter case the adjustments of both plates on the comparator will have to be repeated to allow for the change just made.

With the measured parallax values a the distances A of the control points are computed and compared with those of the plotted points. Discrepancies Δ between these exceeding the amount due to errors in parallax of ± 0.01 mm. would point toward an error in "swing" (Δ_s) during the exposure of the plate, errors in base measure (Δ_b), or toward errors due to both. We may, therefore, express these discrepancies by the equation

$$\Delta = \Delta_s + \Delta_b.$$

If the error in base measure equals b and the error in parallax, due to the "swing of plate," δ, equals $s = f\delta$, we will have the equations

$$\Delta_b = \frac{A}{B} \cdot b,$$

$$\Delta_s = \frac{A^2}{Bf} \cdot s.$$

We can now compute the errors Δ and Δ_1 (discrepancies between the computed and plotted distances A) from the parallaxes of two pictured control points and substitute these values for Δ and Δ_1 in the equations

$$\Delta=\frac{A}{B}\cdot b+\frac{A^2}{Bf}s,$$

$$\Delta_1=\frac{A_1}{B_1}b+\frac{A_1^2}{B_1 f}s,$$

after which the values for the base-line error (b) and the error in parallax (s) may be computed and applied to the base-line and parallax values.

A better way would be to use all the control points, tabulate the errors (Δ) graphically, and find the values for Δ_b and Δ_s by interpolation, as shown on Plate CVII.

The abscissæ of the control points are plotted in their true lengths and the corresponding errors Δ are plotted as ordinates, giving the points 47, 48, 44, 28, 38, 32, 34. A curve passing through the initial point O is laid through this series of points. To separate the ordinates, Δ, of this curve, OC, into the component parts, Δ_b and Δ_s, a tangent OG through O to the curve OC is to be drawn in such manner that the upper sections m, n, o, etc., increase in length with the squares of A ($o=4m$, $p=4n$, $q=4o$, etc.), as the increase in the errors Δ_s is directly proportional to the squares of the distances A and the errors Δ_b increase in the same ratio as the distances A.

With a pair of dividers and a ruler the position of OG may be located tentatively. For an error in the base line, $b=O$, the curve OC will be a parabola, having the parameter $=\frac{B\cdot f}{2\cdot s}$; for an error in swing, $s=O$, a straight line will replace the curve, and $\Delta=A\cdot\frac{b}{B}$.

The lower ordinate section serves for the determination of the base-line correction, $b=\frac{B}{A}\cdot\Delta_b$, and the upper section gives the correction for the parallaxes $s=\frac{B\cdot f}{A^2}\Delta_s$.

The general course of the curve OC will be a criterion of the errors affecting a pair of plates, showing whether they are due to regular causes or whether errors of level adjustments, errors in computation, etc., have crept in also. If no smooth compensating curve may be drawn to harmonize with the series of plotted points, errors outside of those referred to in the preceding paragraphs should be looked for.

A serious error in the swing of the plate may affect the curve in a marked manner. The correction applied to the parallax, as referred to in the preceding, neutralizes only the constant δf. It corrects the position of the principal line with reference to the pictured points, but when there is a decided swing in the plate the parallax, for points to either side of the principal line, will be in error, even after the correction s for the parallaxes has been applied.

After the correction δf has been applied, the plates may yet have the relative positions indicated in Fig. 1, Plate CVI, where points at infinite distance and situated in the principal plane will be pictured in the principal lines of both plates, whereas the images a of a distant point A, lying to one side of the principal plane, will be pictured at a and a_{11}, instead of at a and a_1. In lieu of the correct parallax (x_1-x) we obtain the smaller value $(x_{11}-x)$, referring to Fig. 2, Plate CVI. The error thus remaining, which may be expressed as $\Delta=\frac{x^2}{f}\delta$, increases rapidly with an increase in the length of abscissa; it is positive on one side of the principal line and negative on the other, being $\pm O$ for points on the principal line. It is a prime requisite, therefore, to expose pairs of plates as near as possible in a vertical plane parallel with the base.

After a plate pair has been tested and after the corrections found necessary have been applied the iconometric mensuration may be commenced. The pictured points may be plotted by means of their lines of direction, based on the abscissa values, recorded on the scale *A*, and its horizontal distance from the left station, based on the measured parallax as given on scale *a* of the stereocomparator. The difference in elevation between the station and the plotted point may be computed from the reading of scale *B*. To ascertain the parallaxes of the pictured points the index mark is moved from point to point in the stereoscopic image field, very much in the same way as the telemeter is caried from point to point in the field when reading distances. It is evident that the index mark may readily be moved to bisect points in the image field that would be inaccessible for the ordinary telemeter in the field. The distances, obtainable by moving the index mark in the stereoscopic field, considerably exceed those measured with the telemeter and the time required for obtaining these distances stereoscopically is so short that the advantages of the stereoscopic method over the plane-table and tachymetric methods are out of question for topographic reconnaissance work in rough mountains.

The stereocomparator, furthermore, is peculiarly well fitted for a quick location of points having the same elevation; the index mark may be used to trace out the contours in the stereoscopic field. Points may also be readily located that are in the same frontal plane, in the same plane parallel with the base line. Actual profiles parallel with the picture traces may thus be run out and by locating points to either side of the profile, using the micrometer screw of the binocular microscope for this purpose, terrene strips of 150 to 250 meters width (scale 1:25000) may be developed, which will form the base for the subsequent orographic development of the topography.

The positions of points that have been plotted by the usual method of direction and distance may be checked by referring them to the plotted positions of near-by pictured control points.

The stereoscopic photogrammetric methods evidently offer a wide field for application to ascertain changes that may have occurred during periods of time that are allowed to elapse before taking a new set of pictures from the same base line (or at least from the same vicinity). The examination of two stereoscopic plate pairs of a glacier, for instance, would at once show any change in form or location if the left plate of one pair be examined in the stereocomparator with the right plate of the second pair, both pairs being obtained at different times from the same base line.

Good results may be expected from this method, if applied by the navy, for mapping coast lines without making a landing, by taking simultaneous views of the coast, fortifications, etc., from a vessel (a base line being measured on the deck between the camera stations), noting the position of the vessel on the chart at the time of exposure.

The use of the stereocomparator may also be recommended for recording the positions of moving bodies (army corps, fleets during maneuvers or in time of war), making plans of inaccessible objects, for the mapping of cities, for making profiles, plans, and relief models of areas to be studied for comparative locations of roads, railroads, irrigation plants, etc.

To recapitulate, the actual mapping of the terrene details, based on the examination of stereoscopic picture pairs, may be made:

(1) With relation to a series of control points plotted from data obtained directly with the stereocomparator;

(2) With relation to a series of contours obtained directly from the picture pairs, or

(3) By means of profiles composed of points having the same parallax, i.e., points in frontal planes.

Of the many-fold uses to which the stereocomparator is adapted we may mention stellar surveys, the testing of banknotes, the comparison of scales and their prototypes, comparing facsimiles and replica of various kinds, the study of animals in motion,

migratory-bird flights, changes in the northern lights, cloud elevations, terrene changes due to landslides, volcanic eruptions, inundations, forest fires, etc., for the study of effects produced by bombardments and explosives, changes in sand dunes, etc.

In the preceding paragraphs it was assumed that each pair of plates was not only exposed in the same plane (the plane containing the base line or laid parallel with it), but this plane was also supposed to be *vertical.* The verticality, of course, greatly facilitates and simplifies the iconometric constructions, yet it is not a *sine qua non.* If a plate pair be exposed in the same *inclined* plane, all that has been said about the stereotopographic method still holds good if the angle of inclination of the plane containing both plates during their exposures be measured and taken into account.

If the landscape pictures on the inclined plates could be transferred to vertical plates by photography, the latter could be used on the stereocomparator just as if the plate pair had been exposed in the vertical plane originally.

The inclined-plate position will often be unavoidable in making stereophototopographic surveys from the decks of vessels, and even in mountain work a suitable location for the base line will sometimes necessitate exposures to be made on inclined plates in order to control deep valleys or high elevations from the two base stations.

CHAPTER XI.

PHOTOGRAPHIC OPERATIONS IN THE FIELD.

UNTIL now the principal operations have been considered for obtaining the so-called "latent" or invisible image on the exposed plate, which is still to be converted into the "negative," in which form the terrene image is used, either directly or indirectly, for the iconometric plotting of the pictured topographic features.

The work of developing and fixing the negatives of an extensive photographic survey is best done by a photographic expert who has made special studies and experiments for this purpose. He should be thoroughly familiar with the laws that control the changes, both chemical and physical, which take place in the compositions of the sensitized coatings of the photographic plates, when they are exposed to the action of light, as well as those which control the changes in the chemical compositions of the sensitized films when the plates are immersed in the developing, toning, and fixing baths.

Still, every phototopographer should be sufficiently familiar with the general routine practice of photography to develop some "trial" or "test" plates understandingly and successfully while he is yet in the field.

At least a few plates taken at random from every batch originally packed together and which are likely to have passed through the same conditions during transportation should be developed, while still in the locality where the exposures were made, to feel satisfied that no plates were spoiled and also to feel reasonably assured that the exposures were correctly timed.

The wisdom of developing test-plates, to avoid loss of valuable time and material by incorrect exposures or by the use of spoiled plates, is beyond dispute. If all development of plates be postponed until after the return of the expedition, defective plates cannot be replaced without expending large sums of money, and the results of the expedition may be robbed of much, if not of all, practical value.

Whenever there is danger of losing undeveloped plates through careless and ruthless inspection of baggage on frontiers, or through the inquisitiveness of packers, to whom the transportation of the plates must be intrusted, it is of course advisable to develop *all* the plates of the survey in the field, *pari passu* with the progress of the survey.

The principal records of the season's work, regarding the topography at least, consist in a series of undeveloped plates, and the phototopographer should feel reasonably certain that they are of as good a quality as could be obtained under the conditions of climate and surroundings prevailing at the time of their exposures.

We will give in the following a cursory review of those operations to which an exposed plate is to be subjected before it is converted into the permanent negative, and with which the phototopographer should be familiar to enable him, for the reasons just stated, to develop some test-plates while he is still in the locality where the exposures were made.

I. General Remarks on the Exposure of a Photographic Dry-plate.

When the sensitized coating of a photographic plate is exposed to the action of the rays of so-called white light—solar light—certain effects upon the chemical composition of the coating will be produced, consisting primarily in a reduction of the silver haloids that are embodied in the gelatine coating of the dry-plate into an unstable condition, permitting a deposit of metallic (black)

silver to be readily made upon the plate when the latter is immersed in the so-called "developer" (reducing bath), which converts the light-sensitive "latent image" of the exposed plate into the "negative" of a permanent and stable character.

The greater the intensity of the light that reaches the plate in the camera, or the longer the exposure of the plate to the action of the light-rays, the greater will be the amount of reduced silver.

The quantitative effect, in a given time period, of white light upon the sensitized coating of a photographic plate may differ perceptibly from the quantitative effect of chromatic or color rays, although their qualitative effect upon the silver haloid (bromide of silver) is essentially the same. For short exposures the quantity of reduced silver may be regarded as directly proportional to the duration of the exposure. The "density" of a negative is more or less great according to the larger or smaller amount of reduced silver that has been deposited; density increases directly with the length of exposure.

Photographic dry-plates differ materially regarding their "speed," or their sensitiveness to light action. The speed is generally indicated by the so-called "sensitometer number," ascribed to each emulsion. The same density for two different plates, when photographing the same object under identical conditions, may be attained by giving each plate a different length of exposure, corresponding to its sensitometer number, the less sensitive plate, of course, being given the longer exposure.

Under ordinary conditions, three different stages of exposure may be considered in practical photography:

1. Underexposure;
2. Correct exposure;
3. Overexposure.

A fourth stage, the so-called "period of reversal," may possibly be reached, but this requires so lengthy an exposure that it will rarely be attained, inadvertently, when exposing plates for phototopographic purposes.

An underexposed plate may be recognized by the marked

contrast in the negative between the lights and shadows and a general deficiency in details. Such plates will be of little or no value for iconometric plotting.

An overexposed plate shows little contrast between the lights and shadows and the general details will be weak and flat.

When a plate had been exposed correctly, its scale of gradation in tint, after proper development, will embrace the widest range possible, from pure transparency (white) to black. A negative appears transparent where the photographed object was dark and *vice versa*. The negative should be a true inverse of the original regarding the light gradations.

The source of the light-rays which are emanated by any object in nature may be a threefold one, comprising:

1. Rays of direct sunlight;
2. The less intense rays of diffused skylight;
3. Rays originating from the foregoing two sources, but reaching the subject indirectly after having been reflected from surrounding objects.

The intensity of the light-rays, generally summarized as daylight, is subject to many variations. The sunlight alone will have a variable intensity at different altitudes and under different atmospheric conditions, irrespective of the geographic latitude.

The tendency of aerial perspective is in the direction of diffusion of sharp outlines of distant objects and toward obliteration of details. The skyline of distant mountains becomes merged into the so-called "blue haze." The nearer sea-level the observer is stationed the more indistinct will distant objects become, while in high altitudes, with a relatively dry atmosphere, objects will be discernible, as to form and color, at far greater distances.

Some of the polychromic rays of sunlight, on their passage through the atmosphere, intervening between the observer and the object, will become diffused or absorbed, while others will transverse the same without suffering any perceptible modifications. Color rays near the violet end of the solar spectrum, rays of short wave-lengths, are more largely absorbed by the

atmosphere than those of longer wave-lengths near the red end of the spectrum.

We had seen (Chapter VII) that the component rays of so-called white light after transmission through a lens will be differently refracted and the actinic effects of such refracted rays upon the sensitized films will differ according to their colors or wave-lengths. Those of short wave-lengths, the ultra violet to blue, between the Fraunhofer lines H_1 and F, have by far a more pronounced chemical action upon the silver haloids of the plate coating than light-rays with longer wave-lengths, the green, yellow, orange, and red rays, between and beyond the Fraunhofer lines E and A.

The luminous (optical) effects of the component colors of a landscape upon the eye are not identical with the actinic (chemical) effects upon the photographic plate. The optical effect is governed by the various degrees of tint, hue, or shade that the several parts of the landscape convey to the eye, some parts appearing as light, others in half-light, still others in middle tint, half dark, and dark.

Practical experience, on the other hand, teaches that the various blues and dark greens of the chromatic scale appear darker to the eye than the yellows, the reds, and the lighter shades of green, yet, when a photographic plate is exposed in the camera to both, the combined action of the luminous and actinic light-rays of an illuminated landscape, the actinic action of the blue rays will be more intense on the sensitized film than that of the light-green, the yellow, orange, and red rays. In order to obtain, therefore, a clear and well-defined picture of the violet and blue-colored parts, the exposure will have to be stopped long before the parts having shades of light green, yellow, orange, and red have been reproduced on the negative. The resulting monochrome picture will have a scale of but three-tone gradations—light, half-light, and dark—instead of the scale of five gradations of tone mentioned above.

Thus it may happen, when an ordinary dry-plate is exposed

in the camera, the sky and blue-tinted parts in general will be overexposed if the exposure had been timed correctly for the green, yellow, orange, and red-tinted parts. For the use of the phototopographer who desires negatives showing also the distant details of the landscape clearly and well defined the ordinary dry-plate is inadequate.

II. Orthochromatic Dry-plates and Ray-filters.

In the preparation of the sensitive film of the "isochromatic" (rendering all color values evenly well), or "orthochromatic" plates (rendering the color values correctly), it has been the aim to make them equally sensitive to the actinic action of all color-rays, so that during a properly timed exposure all colors of the subject may be represented upon the finished negative equally correct regarding their respective tints and light values. As yet, attempts in this direction have been only partially successful, however. Orthochromatic plates are indeed made more sensitive to the actinic effects of red, yellow, and light-green rays, but the blue rays remain, even with these plates, considerably more active than the reds and yellows, and to retard their chemical action still more, a so-called "color-screen," or "ray-filter," is interposed between the plate and the subject. A suitable combination of orthochromatic plate and color-screen makes it possible to reproduce landscapes (and colored objects) in better harmony regarding chromatic values, reducing the actinic power of the rays of long wave-lengths and increasing it for the rays of the less refractive end of the solar spectrum.

At present the orthochromatic plates are prepared by imparting color sensitiveness to the gelatino-bromide-silver emulsion of the ordinary dry-plates by the addition of certain color ingredients or "optical sensitizers," like erythrosine, cyanine, rhodamine, eosine, etc. The nearer these optical sensitizers approach a blue shade of color, the more sensitive the plate will become for light-rays of the less refractive end of the solar spectrum.

The addition of erythrosine is said to increase the sensitizing action of the emulsion for light reds, while rhodamine increases the same for light greens, extending well toward the yellow and light orange. Tetrachlor-tetraethyl-rhodamine-chlorhydrate imparts a more powerful sensitizing action for the orange yellow, and green tints. Cyanine has a greater orange sensitiveness than either of the ingredients named, excepting, perhaps, the last-mentioned dye, but the others have the advantage of not materially reducing the general speed or sensitiveness of the plate. Valuable experiments in this direction establishing the foregoing facts have been made by Dr. Eder, Valenta, Mallmann, Scolik, Schumann, Obernetter, and others, who have published formulas for the various optical sensitizers that they recommend individually.

A. Color-screens, or Ray-filters.

The general introduction of color-sensitive plates has been somewhat retarded on account of the necessity of a materially increased length of exposure when using a color-screen, precluding the use of this combination for all instantaneous work.

For phototopographic purposes ray-filters are used from a bright-yellow to a deep-orange tint, varying with the character of the plates and lenses used. In the Canadian surveys, for instance, an orange-colored filter was used with the Zeiss Anastigmat Lens No. 3, Series V, together with Edwards' Isochromatic Medium Plate, while a light-yellow screen (Carbutt's) gave good results in connection with Dallmeyer's W. A. Lens and Carbutt's Orthochromatic Plates (sensitometer No. 23), for the topographic reconnaissance, made by the U. S. Coast and Geodetic Survey, in S.E. Alaska.

Carbutt's (pale-yellow) screens are composed of two thin plano-parallel crystal-glass plates cemented together with balsam and having the color matter between the plates. They are $2\frac{1}{2}$ or $3\frac{1}{2}$ inches square and can be placed in grooved pieces of wood suitably attached to the back of the lens board. The

screen should always be in position when focusing; when not in use it should be kept in a box protected against light. With Carbutt's light color-screen (yellow) the action of the chromatic rays begins between the Fraunhofer lines *C* and *D* and it ends between the lines *E* and *F*.

Dallmeyer's yellow screens are fitted into metal settings which may be attached to the lens mount, close to one side of the diaphragm when a lens doublet is used.

The Bausch and Lomb filter is in the form of a hollow glass cylinder that may be filled with variously colored liquids to suit different optical demands. The plano-parallel ends of these cylinders are made of optically worked glass and the whole is incased in a metal ring that fits over the lens mount.

Theoretically, the color-shade of the screen should decrease in intensity, from the center toward the edge, in the same ratio as the intensity of the illumination of the plate in the camera decreases from the center toward the margin and its form should be spherical, its center of curvature being in the second nodal point of the camera-lens. For all practical purposes, however, distortion, due to the use of a plano-parallel screen, placed at right angles to the optical axis, is imperceptible, particularly when the screen is placed in the nodal plane of the lens and when using a relatively small stop.

Terrene points in the shadows of a landscape receive but partial illumination from the sky and atmosphere and only reflected light from the surfaces of surrounding bodies; the rays reproducing such shadows on the plate will principally belong to the violet end of the spectrum. Hence negatives obtained behind yellow color-screens give the shadows in exaggerated intensity, particularly when photographing mountain views of an Alpine character, since the rarefied air in high altitudes absorbs less light than the air in lower altitudes. The exaggerated contrast between the high lights and shadows in such views makes it desirable to employ specially prepared plates of a thick emulsion coating, which have the further advantage to widen the

range of correct exposure. Thinly coated plates require accurately timed exposures to avoid a characteristic flatness in their negatives.

B. Halation.

The naturally sharp outlines defining dark sections in Alpine views, or objects with marked contrasts, frequently appear blurred and undefined in negatives obtained after a rather lengthy exposure, such condition being caused by a reflex action of rays that have deeply penetrated the emulsion and have been reflected from the glass surface immediately below the plate coating. This effect, known as "halation of the plate," may be greatly reduced by covering the rear surface of the plate with an opaque coating of the same refractive index as that of the glass used for the plate. Plates provided with such protective backings are called "non-halation" or "anti-halation" plates. The backing of non-halation plates should be removed before these plates are subjected to the developing process.

Besides the increase in range of the gradation of tints in a monochrome reproduction of a landscape or multi-colored object, color-screens also materially aid in the prevention of halation when the necessity arises of having to expose a panorama plate directly toward the sun.

To prevent possible side reflection and permit only such rays to reach the plate which are conducive to the production of the image, it is recommended to insert one or more diaphragms in the camera-box and to paint these, like all other interior surfaces of the camera-box, a dull black. Rays reflected by the lens surfaces should likewise be excluded from the interior of the camera. This is effected, in a measure, in the Zeiss Anastigmat Lens by giving the surface of the back lens a strong curvature. For similar reasons certain surveying-cameras (Deville's and that of the U. S. Coast and Geodetic Survey) are provided with a "hood" or "lens shade."

Plates exposed in the field, when well protected against heat

dampness, injurious gases, and, of course, against light, both before and after exposure, will preserve the undeveloped image in the latent stage almost indefinitely.

III. Comparative Light Values and Exposures.

To secure as much detail in the shadows as possible, the plate should be given as lengthy an exposure as it will bear without becoming overexposed. This length depends upon a series of circumstances and conditions; the more important ones are:

1. The intensity of the light that reaches the plate;
2. The sensitiveness of the plate;
3. The speed of the lens;
4. The size of stop used;
5. The color and illumination of the object;
6. The character of the color-screen;
7. The distance of the object from the second nodal plane of the lens.

Success in obtaining clear and well-defined negatives depends largely upon properly timed exposures, demanding care, judgment, and much experience, if the results are to be uniformly successful. Various tables (and diagrams) of comparative light values and comparative exposures have been computed from which much information may be gained simply by inspection, to obtain which without such aid would require much experience, time, and trouble. Such tables and diagrams, of course, vary with the latitude of the place and its altitude above sea-level; both, however, may be neglected for exposures made while the sun is relatively high, say not below 45°. Under this proviso we would have to consider only the conditions of the atmosphere, including the illumination, the hour of day, the season of the year, the rapidity of the plate, the character of the screen, and the lens stop, to ascertain the time for correct exposure.

Any one who has experimented with a certain brand of plate under certain atmospheric conditions, in a known latitude, and

at a certain elevation above sea-level to ascertain the time required for the correct exposure for a certain subject with a certain lens and diaphragm, taking recourse to a table of comparative light values, can readily decide what time should be given a similar plate under the same conditions, with the same lens and diaphragm, at any other hour of the day and on any other day of the year.

For a correct exposure the time given the light for action upon the film should be inversely proportional to the intensity of the light emanated from the subject. A subject, for instance, requiring six seconds' exposure when the intensity of the light be one, would, under identical conditions, require an exposure of two seconds for a light value of three.

The following table contains the comparative exposures for different lens stops and for "open" and "dark" landscapes.

	Comparative Exposures for Different Lens Stops.							
Number of Lens Stop........	2 *F*/5	4 *F*/8	8 *F*/11	16 *F*/16	32 *F*/22	64 *F*/32	128 *F*/45	256 *F*/64
Open landscape (seconds)....	1/32	1/16	1/8	1/4	1/2	1	2	4
Average landscape with fore and background of average color (seconds)............	1/6	1/3	3/4	1½	3	6	12	24

The upper line of this table gives the so-called "Uniform System" numbers of the lens stops or diaphragm apertures, which numbers have the same ratio to each other as the areas of their corresponding stops. The second line expresses the ratio which the stop diameter bears to the focal length (*F*) of the camera.

This table is based on a plate requiring 1 second's exposure when using stop *F*/32 (the diameter of this stop is $\frac{1}{32}$ of the focal length of the lens) for an open landscape. The same brand of plate at the same date and hour and under the same conditions

of illumination would require 1½ seconds' exposure for an average landscape when using stop $F/16$.

Taking the length of exposure at noon, from the middle of April to the middle of September, as unit, the corresponding lengths of exposures for a plate at other hours and at different seasons of the year are given in Scott's table:

Hours A.M.	January 1–15	January 15–31	February 1–15	February 15–28	March 1–15	March 15–31	April 1–15	April 15–30	May 1–15	May 15–31	June 1–15	June 15–30	Hours P.M.
4	—		—		—		—		—		—	30	8
5	—		—		—		—		30	15	14	10	7
6	—		—		—	30	15	12	8	6	5	4	6
7	—		30	15	12	7	6	4	3	2.5	2.3	2	5
8	30	15	10	6	4	3	2.5	2	1.8	1.7	1.5	1.6	4
9	10	6	4	4	2.1	1.8	1.7	1.6	1.5	1.4	1.3	1.3	3
10	5	4	3	1.8	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1.1	2
11	4	3.5	2.5	1.8	1.7	1.5	1.3	1.2	1.1	1.1	1	1	1
Noon	3.5	3	2.5	1.8	1.6	1.4	1.2	1.1	1	1	1	1	Noon
	15–31 December	1–15 December	15–30 November	1–15 November	15–31 October	1–15 October	15–30 September	1–15 September	15–30 August	1–15 August	15–31 July	1–15 July	

We see from this table that the brightest hours of the day are between 11 A.M. and 2 P.M., the light during this time interval having greater actinic power than at any other hour of the day. Views taken between May and August at 5 A.M. or at 7 P.M., for instance, should be given exposures from 10 to 30 times longer than the same subjects would require between the hours 10.30 A.M. and 1.30 P.M. for the same months.

The diagram shown on Plate XCVI represents the comparative lengths of exposure at different hours of the day for the entire year. The abscissæ represent the days of the year from January 1st to December 31st, while the ordinates give the comparative lengths of exposure. This diagram has been constructed for so-called daylight, sunlight, and skylight combined, for a station elevation of 500 feet above sea-level and at a northern latitude of 40°. The lower line, marked "noon curve," gives the comparative lengths of exposure (as ordinates) for all days of the year at noon. The second curve gives similar values for the hours 11 A.M. or 1 P.M., one hour from noon, etc.

Plate XCVII shows similar curves of comparative exposures at a northern latitude of 50°. The full-line curves correspond to an elevation of 5000 feet above sea-level and the dotted curves correspond for the same latitude, but at sea-level.

Experience teaches that the actinic power of light-rays emanating from objects in the shade on a bright day with a deep-blue sky is about ten times as great as at the same hour on the same date, but in dark and threatening weather. A smoky atmosphere reduces the actinic power of light still more; it may then be from twenty to thirty times less than it would be on a bright clear day at the corresponding hour and date. On a bright day with thin fleecy white clouds in the sky it is even more intense, from two to three times greater, than on a cloudless day at the same hour and date.

The following table, by Bunsen and Roscoe, gives the general change in the light intensity as it increases with the altitude of the sun above the horizon:

Altitude of the Sun (above the Horizon in Degrees).	Actinic Power of the Light-rays of Sun and Atmosphere (Combined).	Actinic Power of the Light-rays, Diffused by the Atmosphere (without Sunlight).
0	3.1	3.1
10	17.1	15.1
20	52.6	24.7
30	91.9	31.7
40	122.8	36.1
50	145.5	38.1
60	160.7	39.1
70	170.8	39.6
80	176.4	39.7
90	178.1	39.7

Test Exposures and Trial Plates.

Having selected an orthochromatic plate suitable for the work in view, the observer should make some test exposures to ascertain the speed of the plate combined with the color-screen under known conditions. The exposed test-plates should

be developed with the developer that is to be used for all subsequent exposures. A very satisfactory way to expose these plates is to give one plate several exposures, say four, by withdrawing the slide from the plate-holder a quarter of its length for each successive exposure. By allowing a quarter of a second for each exposure, the four zones exposed on the plate will have received exposures from one to one quarter of a second. A second plate may be similarly exposed, only increasing the final exposure, say to one second, when the four strips will have received the following exposures: $1\frac{3}{4}$, $1\frac{1}{2}$, $1\frac{1}{4}$, and 1 second respectively. All exposures should be made with the same lens stop.

After development of the two trial-plates, it may be found that the second zone of the second test-plate, the one having received $1\frac{1}{2}$ seconds' exposure, may have been the correctly timed strip. Having noted the conditions of light and atmosphere, the hour, date, stop, subject, and whether the time of $1\frac{1}{2}$ seconds was given with or without the color-screen, we can, with reference to comparative exposure and comparative light-value tables or idagrams, ascertain the time for correctly exposing a similar plate under other conditions of illumination and atmosphere at other hours and dates, and, if need be, using different stops.

It may have been found by experiment that a certain correctly timed plate strip required $1\frac{1}{2}$ seconds' exposure with stop $F/11$ for a dark landscape at 2.30 P.M. on June 8th, and we want to ascertain the correct exposure time for the same plate brand, but using stop $F/32$ and photographing an open landscape at 3 P.M. on August 20th.

By inspection we find under stop $F/11$ (page 344), in the table of comparative exposures, for the average or dark landscape the exposure value $\frac{3}{4}$, and the corresponding exposure for stop $F/32$ under open landscape, 1. Now, as our plate required $1\frac{1}{2}$ seconds' exposure for stop $F/11$ and dark landscape it will require 2 seconds for stop $F/32$ and open landscape. From the diagram, Plate XCVII, showing the comparative exposures at different hours and dates, we find that if on June 8th at 1.30 P.M.

the illumination required 1 second's exposure, the same illumination on August 20th at 3 P.M. would require an exposure of $1\frac{1}{2}$ seconds, hence the time required for our plate and subject, on August 20th at 3 P.M., would be $2\times 1\frac{1}{2}=3$ seconds.

For phototopographic purposes a rather slow, double-coated orthochromatic plate is preferable, as it gives a wide range for correct exposure, is less subject to halation, and the negative will have the strength requisite for making good prints.

IV. Development of Orthochromatic Dry-plates.

All photographic plates should be carefully dusted with a soft camel's-hair brush, both after insertion in the plate-holders and again just before immersion in the developing-bath, to remove all dust and foreign matter from the film surface, thus preventing the formation of transparent irregularly shaped spots on the negative. Immediately after immersion in the developer all air-bells or bubbles should be removed from the film surface by gently swabbing the submerged plate with a small tuft of cotton.

The plate is placed, film side up, in the developing-tray and the developer is at once poured over the plate from a graduate or pouring-vessel, with a sweeping motion to cover the entire plate surface simultaneously, and the tray is kept gently rocking to flow the liquid back and forth in a wave-like motion.

When orthochromatic, double-coated non-halation plates are used, development should be prolonged to allow the developer to penetrate the several layers of the film. The high lights in negatives of the ordinary single-coated orthochromatic plates should appear after an immersion of about 30 seconds; for double- and triple-coated plates the developing process should be continued up to 6 and 10 minutes.

If the image flashes up too quickly, the plate no doubt has been overexposed, and it should at once be removed from the developer and rinsed in clear water; development may now be

continued in a diluted developer to which a few drops of a 10 per cent solution of bromide of potassium have been added as a restraining agent. An old developer may be used to advantage for developing overexposed plates.

When the image is rather slow in making its appearance the exposure probably was undertimed, in which case the negative will develop up too strong with clear shadows and no details. The latter may be brought out, in a measure, by a lengthy immersion of the plate in a diluted or old developer, the bath being kept at a temperature of not over 60°. Experience and observation will best teach when the proper stage in the development may have been reached and when the plate should be removed from the bath. The old thumb-rule, to continue development until the image may be dimly outlined on the back of the plate, would lead to overdevelopment if observed for heavily coated plates. The operator may be better guided by stopping development as soon as the "white portions" (the shadows of the original) of the negative begin to change and darken. Weak negatives with clear shadows are generally due to underdevelopment. Too much density often results from development in a developing solution too concentrated or too warm.

Since ortho and isochromatic dry-plates are extremely sensitive to yellow, orange, and, to an appreciable extent, to red light, it becomes necessary to exercise great care in using the ordinary dark-room light in their manipulation. These plates should be exposed only to dark ("Venetian") "ruby light," covered with one or two layers of "non-actinic paper" (Denison's Orange Tissue or Gold Bank Envelope Paper). Even under the exercise of these precautions, the plate in the developing-tray should be kept covered with a cardboard or slab of hard rubber, except when necessary to examine the progress of development. Only enough illumination should be permitted to enter the dark-room or dark-tent as is absolutely necessary to conduct the operations incident to change of plates and their development.

Nearly all manufacturers of photographic dry-plates and printing-papers put up special developers, recommended for use with their films, in the form of powders, tabloids and concentrated stock solutions, with full directions for their application. Amateurs preferring to make up the developing solutions directly from the chemicals had best prepare the same in the form of saturated stock solutions, to be mixed and diluted just before use as needed. In this connection it is well to bear in mind that dried granulated chemicals are far more active than equal weights of the same in crystallized form, the weight of the latter being partly made up of "crystallization water." For instance, dried granular sulphite of sodium has double the strength of the same chemical in crystals, and five parts of carbonate of sodium in the dried state have the same chemical strength as twelve parts carbonate of sodium crystals.

If photochemical solutions are prepared by weights and measures, careful attention should be given to the relative strength of their component parts. Trouble in this respect, however, may be avoided by using a "hydrometer" (the single-degree hydrometer generally used for testing silver solutions is best) for testing the concentration of the solutions, as dried or crystallized chemicals may then be used indiscriminately.

Stock solutions are best put up in limited quantities, as most photo-chemical solutions deteriorate with age. It may be noted here that chemical action may be increased considerably by conducting development under relatively high temperatures, and decreased when working under a temperature lower than 70°, the latter being generally recommended for the best results.

Nearly all developing compounds are composed of two parts, the *developing agent* proper and the *alkaline solution.* Among the developing agents more generally in use we have: Ferrous oxalate, pyrogallic acid, hydrochinon, eikonogen, metol, rodinal, their various combinations, and many others, increasing in number from year to year. They differ in speed, action, keeping qualities, density imparted to the negative, latitude permissible

in the exposure of the plate, etc. After having become familiar with the action of any one developer it is recommended to adhere to its use to insure uniformity in the resulting negatives.

If, in a given developer, the developing agent be used in excess of the correct proportion, too great a contrast between the lights and shadows will result; the development will not be under control, it will progress too fast. An insufficient amount of the developing agent will produce a negative deficient in strength and lacking the qualities essential for good printing. The general development will be slow with the concomitant danger of "frilling," which is the separation of the film from the edges of the glass plate.

The alkaline ingredients of the developing-solution, principally carbonates of sodium (" sal soda ") and potassium, bicarbonate of soda, and sulphite of soda, serve to open the pores of the gelatino-bromide of silver emulsion, permitting a free entrance of the developing agent into the upper layers of the softened plate film, thus producing a more prompt and effective action on the embedded particles of the silver haloids. An excess of the alkaline solution tends to produce a dense negative, imparts a tendency to fog the plate, and often converts the film of the latter into a granular condition.

The progress of development will be materially retarded if an insufficient quantity of the alkaline solution be used. Bicarbonate of soda, being less active than carbonate of soda and carbonate of potassium, is often used, in combination with sulphite of sodium, for developing thinly coated plates to reduce their tendency toward fog formation and to prevent injury to the film. The alkaline solutions are preferably kept in hermetically closed bottles to prevent decomposition, which would soon take place on exposure to the air. Old alkaline solutions, or such containing impure sulphite of sodium, are apt to produce yellow stains on the negative and feshly prepared solutions of pure sulphite of sodium should be used whenever possible.

All chemicals for photographic use should be pure, and it is

recommended to purchase those especially manufactured for photochemical purposes. Some manufacturers of compressed pharmaceutical preparations have extended the tabloid system to photographic preparations. The advantages of the tabloid form to the traveller, explorer, and to the novice in the practice of photography are apparent. Tabloids when prepared by dry compression do not readily decompose; they retain in their fullest energy the qualities of the various ingredients of which they are compounded, and they have reliability, uniformity, and portability in their favor.

A. Water and Water Tests.

The water used in photographic operations should be distilled or pure and free from foreign matter. By reason of its great dissolving power, ordinary water, in the absence of the distilled article, should be boiled for some time and then allowed to cool before decanting it for making photochemical solutions. The following simple tests may be applied to discover the presence of iron, magnesia, lime, etc., in ordinary water:

For Iron: The addition of an infusion of nutgalls to water will show the presence of iron by imparting a grayish color to the mixture. If the liquid turns blue, after the addition of a pinch of prussiate of potash, the presence of iron is unmistakable.

For Magnesia: Reduce a certain amount of water by boiling to $^1/_{20}$th of its original weight, then dissolve a few grains of neutral carbonate of ammonia in this liquid. If a whitish precipitate is formed, after the addition of a few drops of phosphate of soda, magnesia will be present.

For Lime: If two drops of a concentrated solution of oxalic acid be added to a glass of water, the latter will contain lime if a milky appearance be thus produced.

For Alkalies: Water that will change red litmus paper, on immersion in the same, to blue may be considered alkaline.

For Organic Water: Water becoming turbid, after the addition of one tablespoonful of tannin solution (1 part tannin, 4 parts water, and 1 part alcohol) to a tumblerful, will contain organic matter. Such water is unfit for drinking purposes, particularly if the impurities are of animal origin.

For Hardness: If no change be noted after adding a few drops of a solution of good soap in alcohol the water is soft; if it becomes milky in appearance it may be considered hard.

For Carbonic Acid: To half a tumblerful of water add an equal amount of lime-water; if carbonic acid be present a precipitate will be formed and the addition of muriatic acid will cause effervescence.

B. Developers.

There is a distinct relation between the intensity of the light that has acted upon the sensitized emulsion coating of a plate and the actual amount of silver that is deposited upon the plate under the action of the developer and which defines the density of the negative. The laws which control the combined effects of light and developer upon a photographic plate have been studied by many photochemists. The results of the researches made by F. Hurter and V. C. Driffield in England are generally accepted as representing the best discussion on the subject. Capt. E. Deville, in his work on "Photographic Surveying", gives an abstract of the principal papers published by Messrs. Hurter and Driffield, with which every photographer should familiarize himself if he is desirous to obtain a knowledge of the laws of correct exposure and development.

1. Developing with Ferrous Oxalate.

Ferrous oxalate is the best developing agent for phototopographic purposes if the exposed plates are packed away in the field to be developed at some later period. For the develop-

ment of test-plates in the field where the means of transportation are limited, and where, owing to the numerous other duties to be performed, dark-room operations must be reduced to a minimum, developers in the form of dry powders or tabloids will generally be preferred.

Good results are obtainable with the iron developer, even after the exposed plate has been stored away for a long time, before the actual development of the same is undertaken. Ferrous oxalate may furthermore be recommended, because it affects only those particles of the silver haloids that had previously been acted upon by solar light, and because the final metallic silver deposit on the plate shows great uniformity in color. For these reasons negatives developed with the iron developer are particularly well suited for making enlargements by "optical projection."

The products resulting from the oxidation of ferrous oxalate, after an exposed plate has been in the developer a short while, exercise a restraining influence over the progress of development, without, however, stopping it altogether. The plate continues to gain density under the prolonged action of the developer, but the energy of the latter is held under control and the progress of development becomes more and more retarded under the gradual advance of the process of oxidation. The details of the image slowly become visible on the plate under the restrained action of the developer, gradually gaining strength and density, and at full development, when the plate is removed from this bath, the plate coating will have undergone a permanent change, inasmuch as particles of the silver haloid that have not been acted upon by the solar rays practically will have remained unchanged, while those that had been acted upon will become reduced to free silver. The final image on the negative is formed by a more or less gradated series of tones, conditioned by the various thicknesses of metallic black silver deposits that have been formed on the different parts of the plate.

For the development of the plates obtained in connection

with the Canadian surveys, Captain E. Deville uses freshly prepared ferrous oxalate compounded in two stock solutions after the following formulas:

A.

Metric Weight.		Apothecaries' Weight.
30 grammes...	Oxalate of potash..................	1 oz.
90 c.c........	Distilled water (hot)...............	3 oz.
1 gramme....	Bromide of potassium..............	15 grains
$\frac{2}{3}$ c.c........	Acetic acid........................	10 minims

B.

30 grammes...	Sulphate of iron..................	1 oz.
60 c.c........	Distilled water (hot)...............	2 oz.
$\frac{1}{8}$ c.c........	Acetic acid........................	2 minims

These stock solutions, A and B, keep well if bottled separately; they should be mixed for immediate use only. For the normal developer take to each ounce of solution A two drachms of solution B. The plates are developed, a dozen at a time, in grooved hard-rubber boxes, in which they are placed in an upright position.

The formulæ for Dr. Eder's ferrous oxalate developing-bath are as follows:

A.

Metric Weight.		Apothecaries' Weight.
200 grammes..	Neutral oxalate of potassium........	$6\frac{2}{3}$ oz.
800 c.c.......	Distilled water (hot)...............	$26\frac{2}{3}$ oz.

This stock solution should be acidulated with oxalic acid, adding one gramme for every 30 c.c. of the solution.

B.

Metric Weight.		Apothecaries' Weight.
100 grammes..	Protosulphate of iron (crystals)......	$3\frac{1}{3}$ oz.
300 c.c.......	Distilled water (hot)...............	10 oz.
$\frac{1}{3}$ c.c.......	Sulphuric acid....................	5 minims

Mix in the order given, adding the acid last. These solutions are good keepers when bottled separately, and they should be mixed (cold) for immediate use only. For the normal de-

veloper and for correctly timed exposures take volumes of A and 1 volume of B and mix in a graduate.

(a) Restraining the Ferrous Oxalate Development.

C.

Metric Weight.		Apothecaries' Weight.
10 grammes...	Bromide of potassium..............	$2\frac{1}{2}$ drachms
100 c.c........	Distilled water....................	$3\frac{1}{3}$ oz.

By adding a few drops of this solution C, termed a restrainer, to the normal iron developer, given above, the development of the latent image will be kept under control. A moderate overexposure of a plate may thus be neutralized by adding from five to ten drops of solution C to the ferrous oxalate developer, which will check the general progress of development sufficiently to impart density to the plate and to allow the details to appear in the high lights before the shadows become overdeveloped.

The simultaneous appearance of lights and shadows on the plate (" the flashing-up " of the image) immersed in the developing-bath would be indicative of overexposure, and the plate should be immediately removed from the developing-tray, be well rinsed in soft running water and be subjected to one of the following means of " retarding " development:

1. Reducing the sulphate of iron solution (against the " normal " amount of oxalate of potash solution);
2. Reducing the temperature of the " normal developer ";
3. Increasing the bromide of potassium (or other bromide salt used);

For the development of overexposed plates it is advisable to withhold about 30 c.c. (1 oz.) of solution B in a separate graduate and add from 2 to 4 c.c. (30 to 60 minims) of solution C gradually pouring enough of this mixture to the developer in the tray to produce the desired density in the plate. Additions to the developer are preferably made after the latter

has been poured off the plate into a pouring vessel, flooding the plate with the modified developer homogeneously mixed.

4. Diluting the "normal developer" with water;
5. Using an old (already used) developer.

(b) Accelerating the Ferrous Oxalate Development.

The application of so-called "accelerators" overcomes, in a measure, the effects of underexposure. They may also be of value when developing plates representing subjects of great contrasts, or in all cases where the normal developer would produce too harsh and too dense a negative. The following means for accelerating development may be employed.

1. Increasing the sulphate of iron solution (against the "normal" amount of oxalate of potash solution);
2. Increasing the temperature of the "normal developer";
3. Using a freshly prepared and slightly concentrated solution of the "normal developer";
4. Adding a *very little* hyposulphite of sodium to the "normal developer."

About three ounces of a developer, when mixed ready for use, will suffice for the development of a 4×5, and four ounces will be required for a 5×8 in. plate. When several plates are to be developed it is best to prepare a larger quantity of the normal developing mixture at one time and develop a dozen plates at once.

After the proper stage in the development has been reached, the plate should be well rinsed in clear running water, then to be placed in the following so-called "clearing solution," which serves to prevent the precipitation of iron from the developer into the upper layer of the plate film.

D.

Clearing Solution.

Metric Weight.		Apothecaries' Weight.
150 c.c.	Saturated solution of alum	5 oz.
4 c.c.	Citric acid	1 drachm
150 c.c.	Distilled water	5 oz.

The negative is submerged in this bath from three to five minutes, after which it is again rinsed in clear running water to remove any deposit that may still adhere to the film surface, to be finally placed in the "fixing-bath."

2. Pyro Developer.

A good "pyro" developer may be made in two solutions:

A.

Alkaline Solution.

Metric Weight.		Apothecaries' Weight.
360 c.c.	Distilled water	60 oz.
30 c.c.	Carbonate of sodium (crystals)	5 oz.
60 c.c.	Sulphite of sodium (crystals)	10 oz.

To prepare this solution with the "hydrometer," mix equal parts of:

Carbonate of sodium solution, testing	40 degrees
Sulphite of sodium solution, testing	80 degrees

B.

Pyro Solution.

Metric Weight.		Apothecaries' Weight.
4 c.c.	Sulphite of sodium (crystals)	1 drachm
180 c.c.	Distilled water	6 oz.

After the sulphite of sodium has been dissolved in the 6 oz. of water, add acetic acid to this solution until the liquid turns blue litmus paper red, then add:

Metric Weight.		Apothecaries' Weight.
30 c.c.	Pyrogallic acid	1 oz.

For the "normal developer" mix:

Metric Weight.		Apothecaries' Weight.
4 c.c.	of B (pyro solution)	1 drachm
60 c.c.	of A (alkaline solution)	2 oz.

For winter use, dilute this with 60 c.c. (2 oz.) of tepid distilled water, whereas for summer use, dilute with 90 to 150 c.c. (3 to 5 oz.) of cold distilled water.

Both solutions should be kept in well-stoppered bottles. If the negatives show yellow stain a new solution A should be made or a freshly prepared sulphite of sodium should be used.

A smaller quantity of sulphite of sodium in solution A will produce a warmer tone, a larger quantity a grayish-blue to bluish-black tone. An increase of A in the normal developer mixture may bring out detail in an underexposed negative. If the high lights in the negative are flat more of the pyro solution (B) may be used, if they are too intense less may be used.

If too little of solution B be used the alkali will be in excess and a foggy negative may be the result.

Pyrogallic acid, being a strong poison, should be carefully handled, clearly labeled, and securely stored.

3. Metol Developer

may be made in either one or two solutions, both keeping well. The two-solution developer, however, is preferable, as it not only gives a better control over the progress of development but it also gives the means for developing overexposed plates by adding a little of solution B to the "normal developer," or by using solution A alone (diluted) if the plate was greatly overexposed.

A.

Metric Weight.		Apothecaries' Weight.
1000 c.c.	Distilled water	10 oz.
15 grammes	Metol	75 grains
120 grammes	Sulphite of sodium (crystals)	$1\frac{1}{4}$ oz.

Dissolve the metol in water before adding the sulphite of sodium.

B.

Metric Weight.		Apothecaries' Weight.
1000 c.c.	Distilled water	10 oz.
150 grammes	Carbonate of soda (crystals)	1.75 oz.
1.5 grammes	Bromide of potassium	8 grains

For the normal developer take:

Solution A,	1	volume
" B,	1	"
Water,	1	"

Metol developer may be used repeatedly. An old developer is to be recommended for overexposures. If the plate shows a tendency to fog add from 10 to 20 drops of a 10 per cent solution of bromide of potassium to the developer.

For correct exposures the image should appear in detail within from 4 to 10 seconds and development should be complete in 4 or 5 minutes.

As the density of the plate is somewhat reduced in the fixing-bath development should be carried on a little further than one would otherwise do.

For underexposed plates the normal developer should be diluted.

4. Metol Bicarbonate Developer

is to be recommended for its excellent keeping qualities and uniform results. It may be used repeatedly without materially affecting the general progress of the development. The bicarbonate of soda makes this developer very safe in action, preventing injury to the film and fogging of the plate.

Metric Weight.		Apothecaries' Weight.
10 grammes...	Metol..........................	1 oz.
600 c.c.	Distilled water....................	60 oz.

Thoroughly dissolve the metol in the water and then add:

Metric Weight.		Apothecaries' Weight.
60 grammes...	Sulphite of soda (crystals)..........	6 oz.
30 grammes...	Bicarbonate of soda...............	3 oz.

To prepare this developer with the hydrometer, mix:

Metric Weight.			
300 c.c.	(30 oz.)	Sulphite of soda solution testing....	75 deg.
300 c.c.	(30 oz.)	Bicarbonate of soda solution testing..	50 deg.
10 c.c.	(1 oz.)	Metol dissolved in 120 c.c. (12 oz.)...	Water

5. Hydrochinon Developer.

A.

Metric Weight.		Apothecaries' Weight.
600 c.c.	Distilled water (hot)	20 oz.
120 grammes	Sulphite of soda (crystals)	4 oz.
4 grammes	Sulphuric acid	1 drachm
23⅓ grammes	Hydrochinon	360 grains
2 grammes	Bromide of potassium	30 grains

Diluted with enough water to make up to

Metric Weight.	Apothecaries' Weight.
960 c.c.	32 oz.

B.

60 grammes	Carbonate of potash	20 oz.
60 grammes	Carbonate of soda (crystals)	2 oz.

With enough water to make up to

Metric Weight.	Apothecaries' Weight.
960 c.c.	32 oz.

C ("Accelerator").

30 grammes	Caustic soda	1 oz.
300 grammes	Water	10 oz.

D ("Restrainer").

14 grammes	Bromide of potassium	½ oz.
150 c.c.	Water	5 oz.

For the normal developer take

Metric Weight.		Apothecaries' Weight.
30 c.c.	Solution A	1 oz.
25 c.c.	" B	¾ oz.
120 c.c.	Water	4 oz.

The working temperature of this developer should not vary much between 65° and 75°.

For underexposure add a few drops of solution C to the normal developer
" overexposure " " " " " " D " " " "

More of solution A (as given for the "normal developer") will increase the density and more of solution B produces an increase in detail.

Should the negative, after development with hydrochinon, show yellow stain, it may be cleared and intensified, if need be, by immersion in the following bath:

E.

Bichromate of potassium	10 parts
Hydrochloric acid	10 "
Water	1000 "

The stained negative is kept in this solution until it appears completely bleached, when it should be well rinsed in running water. If the bleached negative be now developed anew no trace of fog will appear; redevelopment should be carried on until the desired strength and density may be attained.

The following *hydrochinon developer* is recommended by L. E. Jewell for photographing clouds with a ray-filter:

A.

Metric Weight.		Apothecaries' Weight.
30 c.c.	Hydrochinon	1 oz.
150 c.c.	Sulphite of sodium (crystals)	5 oz.
750 c.c.	Distilled water (hot)	25 oz.
7 c.c.	Alcohol (95%)	¼ oz.

After the sulphite of sodium has been dissolved in hot water add the hydrochinon and shake well. Filter the solution, add the alcohol, and again shake well.

B.

Metric Weight.		Apothecaries' Weight.
30 c.c.	Carbonate of potassium	1 oz.
30 c.c.	Ferrocyanide of potassium	1 oz.
360 c.c.	Distilled water	12 oz.

The ferrocyanide of potassium acts as an accelerator for the hydrochinon. For the normal developer take

Metric Weight.		Apothecaries' Weight.
90 c.c.	Solution A	3 oz.
30 c.c.	" B	1 oz.

adding from 6 to 10 drops of a 10 per cent solution of bromide of potassium to this mixture.

Development may be begun with the "normal developer" and if signs of over or underexposure are noted the developing-bath should be modified to the following mixtures:

For overexposure:	3½ volumes sol. A;
	1 volume sol. B;
	½ volume of a ten per cent bromide of potassium solution.
For underexposure:	3 volumes sol. A;
	1 volume sol. B, omitting the bromide of potassium sol.

In changing from one of these developers to the other the plate had best be rinsed in clear water, although this would not be necessary when changing the plate from the underexposure bath to the normal developer, nor when transferring the plate from the normal to the overexposure bath.

6. Metol Hydrochinon Developer.

For use in winter, dissolve in the order given:

Metric Weight.		Apothecaries' Weight.
7 grms.	Metol.	¼ oz.
7 grms.	Hydrochinon.	¼ oz. in
2400 c.c.	Distilled water.	80 oz., then add
120 grms.	Sulphite of soda (crystals).	4 oz.
75 grms.	Carbonate of soda (crystals).	2½ oz.

To prepare this solution with the hydrometer, mix in the order given:

Metric Weight.	
600 c.c.	(20 oz.) Sulphite of soda solution testing. .60 deg.
600 c.c.	(20 oz.) Carbonate of soda solution testing. .30 deg. with 7 grammes (¼ oz.) metol and 7 grammes (¼ oz). hydrochinon dissolved in
1200 c.c.	(40 oz.) Water.

For summer use this normal developer should be diluted with an equal quantity of water to keep the development under good control. If the negatives show too much contrast less hydrochinon and more metol may be taken.

7. Bromo-Hydrochinon Developer.

Bromo-Hydrochinon Developer recommended for developing overexposed plates and for producing density in the negative.

A.

Metric Weight.		Apothecaries' Weight.
750 c.c.	Distilled water (hot)	25 oz.
90 grammes	Sulphite of soda (crystals)	3 oz.
15 grammes	Hydrochinon	$\frac{1}{2}$ oz.
7 grammes	Bromide of potassium	$\frac{1}{4}$ oz.

B.

750 c.c.	Distilled water	25 oz.
180 grammes	Carbonate of soda (crystals)	6 oz.

For the normal developer take equal volumes of A and B. If the plate shows signs of underexposure it should be immersed in a freshly prepared and diluted developer, and if sufficient detail does not appear in this bath, the plate should be removed to another tray containing water to which a little of the alkaline solution (solution B) has been added, leaving the plate in this bath as long as an increase in detail may be noted. If still weak, development may be finished in a fresh developer.

8. Eikonogen Developer.

A.

Metric Weight.		Apothecaries' Weight.
15 grammes	Eikonogen	1 oz.
60 grammes	Sulphite of sodium (crystals)	4 oz.
0.3 gramme	Bromide of potassium	10 grains
900 c.c.	Distilled water	60 oz.

B.

45 grammes	Carbonate of soda	3 oz.
300 c.c.	Distilled water	20 oz.

For the normal developer take 3 parts of solution A and 1 part of solution B, adding 1 drop of a 10 per cent solution of

bromide of potassium to each 30 c.c. (each oz.) of mixed developer.*

If the "acid fixing-bath" be used after development with eikonogen the negatives are apt to be marred by semi-transparent streaks.†

9. "EIKO-CUM-HYDRO" DEVELOPER.

A.

Metric Weight.		Apothecaries' Weight.
600 c.c.	Distilled water (hot)	20 oz.
120 grammes	Sulphite of soda (crystals)	4 oz.
22 grammes	Eikonogen	330 grains
10.5 grammes	Hydrochinon	160 grains

adding enough water to make up to

Metric Weight.	Apothecaries' Weight.
960 c.c.	32 oz.

B.

600 c.c.	Distilled water	20 oz.
60 grammes	Carbonate of potash	2 oz.
60 grammes	Carbonate of soda (crystals)	2 oz.

adding enough water to make up to

Metric Weight.	Apothecaries' Weight.
960 c.c.	32 oz.

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* For developing bromide paper prints add 2 parts distilled water to the normal developer as given here. The developer should be renewed after each 4 to 6 prints have been developed.

† The following "fixing-solution" should be used with this developer for both plates and bromide prints, as it prevents all possibility of the developer staining the negative:

Metric Weight.		Apothecaries' Weight.
60 grammes	Hyposulphite of soda	4 oz.
15 grammes	Bisulphite of sodium	1 oz.
300 c.c.	Distilled water	20 oz.

This fixing-solution remains colorless after repeated use.

For the normal developer take

Metric Weight.		Apothecaries' Weight.
30 c.c.	Solution A.	1 oz.
15 c.c.	Solution B.	4 drachms
90 c.c.	Distilled water.	3 oz.

More of solution A would increase the density of the negative and more of solution B would tend toward an increase in detail.

10. Amidol Developer.

Metric Weight.		Apothecaries' Weight.
600 c.c.	Distilled water.	20 oz.
4 c.c.	Sulphurous acid	1 drachm
15 grammes	Sulphite of soda, granular, dry	4 drachms
3 grammes	Amidol.	46 grains

Dissolve the chemicals in the water in the order given. With this developer the image should appear rather quickly with full intensity and a wide gradation of tones.

C. Fixing the Negative.

After removal from the "clearing-bath," the negative is placed in the "fixing-bath" to preserve the developed image, to render the negative light-proof.

After the proper stage in the development of the plate has been reached, by immersion in one of the preceding developers, in the dark-room, the negative should be well rinsed in clear running water to remove all traces of the developing and clearing solutions. It may next be placed in the "clearing-bath" given under "iron developer" (ferrous oxalate), solution D. This bath should not be omitted after development with ferrous oxalate, but it may be omitted when using most of the other developers. After removal from the clearing-bath the negative should again be rinsed in clear water before it is subjected to the "fixing-bath."

Metric Weight.		Apothecaries' Weight.
4 c.c.	Sulphuric acid	1 drachm
480 grammes	Hyposulphite of soda	16 oz.
60 grammes	Sulphite of sodium (crystals)	2 oz.
30 grammes	Chrome alum *	1 oz.
1920 c.c.	Distilled water (warm)	64 oz.

This acid fixing-bath should be mixed in the following order: Dissolve the hyposulphite of soda (16 oz.) in 1440 c.c. (48 oz.) of warm distilled water, the sulphite of sodium crystals (2 oz.) in 180 c.c. (6 oz.) water. Next dilute the sulphuric acid (1 drachm) with 60 c.c. (2 oz.) water and pour this slowly into the sulphite of sodium solution and add this to the hyposulphite of soda solution. Now dissolve the chrome alum (1 oz. in summer and ½ oz. in winter) in 240 c.c. (8 oz.) of warm distilled water and add this solution to the bulk of the mixture, when the fixing-bath (after cooling) will be ready for use.

This fixing-solution is a good keeper and will not discolor until after repeated use. It clears the shadows of the negative and hardens the film, thus materially preventing "frilling" (separation of film edge from glass surface) in the final washing.

The negative should be kept in this bath until the last trace of the milky-white appearance of silver bromide, when examined from the back of the negative, has entirely disappeared and the shadows have become perfectly transparent. This should require an immersion of about 5 minutes. The negative has now become light-proof and it should be thoroughly rinsed in clear running water for at least one half hour, or when the water is cold, for fully one hour, to free the film from any trace of the hyposulphite. Before removal from the water the film surface should be swabbed with a wad of cotton, again rinsed, and finally be placed in rack to dry spontaneously. If no running water is available the washing may be done in ten to fifteen changes

* The given amount is for use in summer. In winter only 15 grammes (4 drachms) chrome alum should be taken. An excess of alum may cause a precipitate to form on the negative, imparting a mottled appearance to the latter.

of water, transferring the negative from one tray to the other and refilling each tray with fresh water after passing the negative from tray to tray at intervals of five to ten minutes.

It is most important that every trace of hyposulphite of soda be eliminated in the final washing to impart keeping qualities to the negative. Any subsequent formation of a crystallized coating of the film, followed by a gradual fading of the image, may generally be regarded as the direct result of an imperfect removal of the hyposulphite of soda in the final washing.

1. Tests for Presence of Hyposulphite of Soda.

To ascertain whether the hyposulphite of soda may have been thoroughly removed from the film of the negative the following tests may be applied.

The simplest test for presence of "hypo" in the last washing is made by adding a few drops of the following solution (Prof. Boettcher's test) to a little of the water drained from the negative:

Metric Weight.		Apothecaries' Weight.
0.2 gramme	Permanganate of potash..........	3 grains
1 gramme......	Caustic soda..................	15 grains
460 c.c...........	Water..........................	16 oz.

If "hypo" be still present the red color of the mixture will be changed to green.

This solution should be kept in a well-stoppered bottle incased in a light-proof wrapper or box. This test is generally considered very satisfactory, as the quantity of "hypo" left in the pores of the film must be very small indeed if the pink or red colored solution does not change color within a few minutes after mixing the drainings from the plate with the permanganate solution.

Another test is as follows:

Beat up a piece of starch, about the size of a pea, with $\frac{1}{4}$ oz. of water and boil in a test-tube to a clear jelly. To this add

one drop of tincture of iodine, which will produce a dark-blue color. Now fill another test-tube with the drainings from the negative and add one drop of this blue solution, stirring the mixture well. If "hypo" be present the blue color will be discharged.

Should the final washing of the negative have to be cut short, on account of "frilling of the film," during warm weather and in the absence of ice, or should it have to be interrupted for any other reason, it is recommended to place the negative in a freshly prepared "clearing-bath" (solution D, given under ferrous oxalate developer), or in a 1:30 solution of bromine in water, to neutralize and destroy any "hypo" that may still be retained in the surface layer of the film.

2. Drying the Finished Negative.

Negatives are best dried in a cool, dry atmosphere, preferably under a mild draft. In a warm, damp, or wet climate the drying of the finished negative would proceed too slowly, greatly increasing the density of the film, particularly toward the center of the plate, which generally dries last. Under such adverse conditions the drying of the films may be accelerated by flowing proof alcohol over the film a few times before placing the negative in the rack to dry. Heat, however, should never be applied to the negatives for purposes of drying, as it liquidizes the soft gelatine coating. Great care should be exercised not to interchange the trays and vessels used for the various photochemical solutions.

3. Intensification of a Negative with the Aid of Metallic Salts.

With correct exposure and development intensification need not be resorted to. Light somewhat retards the process of intensifying, and it is advisable to conduct the operation in the dark-room, or at least in subdued light. A negative that had been

dried after fixing is more readily acted upon by the intensifier than one that has just been removed from the washing-tank.

Should the final negative be too thin for good printing it may be intensified, after thoroughly washing to eliminate all traces of "hypo," as previously noted, by subjecting it to the following treatment:

Pour a sufficient quantity of a saturated solution of bichloride of mercury in water into a solution of 37 grammes ($1\frac{1}{4}$ oz.) iodide of potassium in 180 c.c. (6 oz.) water until the point be reached when the forming red precipitate can no longer be dissolved by shaking. No more bichloride of mercury solution should be added than just enough to make the solution a slight shade turbid.

Now add 28 c.c. (1 oz.) hyposulphite of soda, dissolve, and add enough water to make up 600 c.c. (20 oz.) of this intensifier. Just before use dilute one part of this intensifier with three parts of water. The weak negative is submerged in this diluted solution, exercising care not to carry the intensification too far, although the negative may be reduced in a measure by again placing it in the fixing-bath for a short while. If the negative was not perfectly "fixed" before subjecting it to the action of the intensifier it will be marred by a yellow stain.

4. Intensification with Silver Cyanide.

After having washed the weak negative thoroughly for half an hour in clear running water it should be immersed for ten minutes in a five per cent solution of alum and again thoroughly washed before applying this intensifier.

A.

Metric Weight.		Apothecaries' Weight.
16 grammes....	Bichloride of mercury............	240 grains
16 grammes....	Chloride of ammonia............	240 grains
600 c.c..........	Distilled water..................	20 oz.

B.

16 grammes....	Chloride of ammonia............	240 grains
600 c.c..........	Distilled water..................	20 oz.

C.

Metric Weight.		Apothecaries' Weight.
4 grammes	Nitrate of silver	60 grains
60 c.c.	Distilled water	2 oz.

This nitrate of silver solution is poured, while stirring, into the following solution:

Metric Weight.		Apothecaries' Weight.
4 grammes	Cyanide of potassium, C.P.	60 grains
180 c.c.	Distilled water	6 oz.

The cyanide of potassium serves as a fixing-agent; it is a very strong poison and the solution C should be labelled "poison" and carefully stored.

To intensify the negative enough of solution A is flowed over it to completely submerge the film. It is subjected to this bath sufficiently long to either partially or completely whiten the film, according to the degree of density desired. After removal from this bath the plate should be carefully rinsed and immersed in solution B for one minute, again be rinsed and then be placed in the cyanide solution (C), where it is kept until the color of the film is changed to a dark brown or black, when it should be removed, thoroughly washed in running water, and placed in rack to dry. The solutions A and B should be thrown away when once used, while the cyanide solution (C) may be returned to its bottle to be used again.

5. Prof. R. E. Liesegang's Intensifer.

Prof. Liesegang recommends the following solution for the intensification of underdeveloped negatives:

		Apothecaries' Weight.
Sol. I	Sulphate of copper	75 grains
	Bromide of potassium	75 "
	Water	$6\frac{1}{2}$ oz.
Sol. II	Nitrate of silver	91 grains
	Water	4 oz.

After the negative, which may be found too thin to print well, has been washed from three to five minutes in running water to remove every trace of hyposulphite of soda (see Prof. Boettcher's "hypo" test) it is placed for ten minutes in solution I until thoroughly bleached. The longer the negative remains in this bath the greater the final density will be; therefore this part of the process should be carefully watched. Still, should the intensification be too marked, the density may again be reduced with the usual fixing-bath of "hypo."

After removal from solution I the negative is again rinsed in running water, or washed in five changes of water for ten minutes, and it is then placed in the nitrate of silver solution until it becomes thoroughly blackened (no white spots should be apparent when viewed from the back). The intensified negative is now washed for at least one hour in frequent changes of water; in running water half an hour will probably suffice.

A negative that had already been dried after fixing is more readily acted upon than one that has just left the washing-tank. Light retards the process materially and intensification is best conducted in the dark-room, or at least in subdued light.

6. Intensifying Negatives without the Use of Metallic Salts.

After a thorough washing in running water the negative is immersed in the following solution:

Metric Weight.		Apothecaries' Weight.
0.3 gramme	Potassium bichromate	5 grains
0.6 gramme	Potassium chloride	10 grains
0.25 c.c.	Hydrochloric acid	4 minims
30 c.c.	Distilled water	1 oz.

Under the action of this solution the silver deposit on the negative is converted into chloride of silver. The plate is retained in this bath until the image appears well bleached, when it is removed and thoroughly washed in clear running water to eliminate the chromium salts from the film. The negative may

now be redeveloped in any developer. Some operators recommend soaking the plate in a dilute solution of sulphurous acid or acid metobisulphite to facilitate the elimination of the chromium salts in the washing between the bleaching and redeveloping.

Pyro-soda, pyro-ammonia, metol, and pyro-metol developers give a considerable increase in density when used for redevelopment with this method of bleaching the image of a weak negative

7. Reducing the Density of a Negative.

Brown and yellowish stains and also a certain iridescence of the film surface may all be caused by having the developing, bath too warm, too strong in alkali for the plate, or by having used the *plain* "hypo" solution in fixing the negative. The same defects may also be caused by using too old a solution in the fixing-bath, or when the latter has been used too often, and sometimes, too, by an insufficient fixing of the negative. A weak solution of perchloride of iron will remove the yellow stains when this bath is followed by an immersion in the acid fixing-bath.

Density in a negative, brown stains, and the metallic iridescence may all be removed by applying the following "reducing solution." Dissolve

1 part of red prussiate of potash in
15 parts of water.

Wrap the bottle containing this solution in yellow paper, to delay decomposition of the solution by the effects of the light, then dissolve

1 oz. hyposulphite of soda in
15 oz. water.

Add from one half to one ounce of the red prussiate solution to the above hyposulphite of soda solution immediately before use and place the negative in this bath directly after fixing.

A dry negative should first be soaked in water for a few minutes. Watch the negative carefully while it is in this reducing solution, rocking the tray and avoiding strong light during the immersion, and remove it to running water at once when it has been sufficiently reduced or cleared.

Great care should be exercised to keep the trays and the vessels as clean as possible and never to interchange them when developing and fixing plates. All vessels used for developing should never be used for any other purpose and the fixing-tray should never be used for developing.

8. Cooling-solutions.

To accelerate the drying of the films in a damp or wet climate the plates may be immersed, just after the final washing, in a bath composed of equal parts of water and alcohol before they are placed in the rack to dry. All negatives, when dried slowly in a damp and warm atmosphere, will become more intense than when dried spontaneously in a draught or in a cool current of air.

Should the conditions be unfavorable enough to require artificial heat for drying the films, it is recommended to immerse the negatives from six to ten minutes in a solution of one part of Woodbury Antipyr in ten parts of water, after which they are rinsed and placed in the rack to dry. This solution may be used repeatedly.

When the development of plates has to be carried on during very warm weather in localities where neither ice nor cold water is obtainable, the several baths may be kept cooled by setting their trays in shallow vessels that are filled with some cooling-solution, of which we may enumerate the following:

1. One part of nitrate of sodium and four parts of water.
2. One part nitrate of ammonia and one part water.
3. One part sulphocyanate of potassium and one part water.
4. Three parts nitrate of sodium and four parts water.

5. One part chloride of potassium and four parts water.
6. Three parts sulphate of sodium and two parts diluted nitric acid.
7. Nine parts phosphate of sodium and four parts dilute nitric acid.
8. One part sal ammoniac, one part saltpeter, and one part water.
9. Five parts sal ammoniac, five parts saltpeter, and sixteen parts water.
10. Eight parts sulphate of sodium and five parts concentrated sulphuric acid.

D. Negative Varnish.

For a better preservation of the negative, its film may be protected by a thin and uniform coating of varnish, to be applied after the film has become thoroughly dried and hardened. The dry negative should be carefully dusted and held near a fire until it is uniformly warm. It is now balanced on the finger-tips of the left hand, film side up, and a small portion of the varnish is poured on the film surface, gradually turning and tipping the plate to cause the varnish to flow to each corner, covering the entire plate but not going over the same place twice. The plate is now kept warm, still holding it in a horizontal position, under a gently rocking motion, until the varnish has dried without leaving lines or ridges.

A colorless and transparent varnish may be made by dissolving one ounce soft copal in ten ounces benzine.

A good negative varnish that will permit of retouching the negative may be prepared after the following formula:

Metric Weight.		Apothecaries' Weight.
10 grammes	Amber powder (melted)	150 grains
6 grammes	Unvulcanized rubber	90 grains
1750 c.c.	Chloroform	50 drachms
1750 c.c.	Benzole	50 drachms

The proportion of benzol added determines the degree of "mat" that may be imparted to the dry coating of this varnish.

V. Photographic Printing.

Photographic printing is the process of obtaining positive copies from a negative, on specially prepared paper (or other sensitized material), by means of light transmitted through the negative.

The printing process is as follows:

Place the printing-frame, face downward, on a table and remove the backboard. Lay the negative, which should be perfectly dry, film side up, in the frame and on this place a sheet of sensitized paper, face down, in contact with the film. This paper may be covered with a blotting-paper or piece of thin felt, after which the back of the frame is replaced and clamped in position. The frame should now be carefully turned over, and any spots that may be on the glass surface should be removed before exposing the negative to the light. These operations may be conducted in the subdued light of a room when using so-called "printing-out" papers, but even this paper should not be exposed too long to such light and not at all to the direct rays of any light.

The progress of the printing should be examined occasionally, in subdued light, by opening one side of the backboard of the frame and raising one end of the paper. The printing should be a trifle darker than is desired for the final picture, and darker when toning for blue-black tones than when toning for warm-brown tones. If not sufficiently printed the backboard is again closed and carefully latched. Only one side of the back of the frame should be loosened for examination of the print to maintain perfect registry between the paper and the negative.

Weak negatives should be printed in diffused light by covering the printing-frame with a sheet of tissue-paper (or with several

thicknesses if required). Strong and dense negatives are best exposed to direct sunlight. It is important to print a shade deeper than required for the finished picture, as the print will always bleach somewhat in the toning and fixing process.

Should the whites darken before the shadows become bronzed, when printing in direct sunlight, it may be taken as an indication that the negative is too weak for printing in intense light and its prints should be made in the shade or in diffused light.

Should the shadows be fully bronzed before details in the high lights appear, when printing in diffused light, it is a sign that the negative is sufficiently dense to require printing in sunlight.

To reduce overprinted pictures an old fixing-solution to which a few drops of a saturated solution of ferrocyanide and ammonia have been added may be recommended.

Prints sufficiently exposed may be collected in a light-proof drawer or in a dark receptacle until a number are ready for toning. There is a large variety of printing-papers in the market for obtaining positive copies from negatives, and special directions for their use and manipulation accompany each brand. They may be divided into two groups. The first, comprising all papers requiring special developing to bring out the latent image, are known as *developing-out* papers. These undergo the same process as a photographic plate after exposure to bring out and fix the image.

The second group comprises all so-called *printing-out* papers (mostly gelatine or collodion papers), the image becoming visible during the printing.

The papers of the first group ("developing-out" papers) are mostly very sensitive and the actinic action of the light on their sensitive silver salt is so rapid that these papers should be manipulated in the dark-room only. The printing, too, is best done in the dark-room with artificial light. These papers have the advantage that they give ready means for obtaining prints at any time irrespective of the weather, and most of them

are invaluable for enlarging purposes, enabling the operator to make prints of almost any size from relatively small negatives. The so-called bromide, platinum, and platino-bromide papers are well suited for making direct enlargements from phototopographic negatives. Such enlargements are preferably used in iconometric plotting in place of the small contact prints.

The papers of the second group are of special value for making contact prints in the field; they are less sensitive to the light than the "developing-out" papers and only require toning and fixing after removal from the printing-frame. We find a large variety of these papers in the market, with special directions for their manipulation and use.

The older and still popular "printing-out" paper known as "silver-printing," "albumenized" or "sensitized albumen" paper is not as sensitive as most of the modern "printing-out" papers. It is coated with albumen and sensitized with a solution of nitrate of silver.

Shortly before placing this paper in the printing-frame it should be *fumigated with ammonia vapors*, thus increasing the brilliancy of the prints and the sensitiveness of the paper as well as reducing the time required for the actual printing and facilitating the subsequent process of toning by reducing any tendency toward "blistering" (separation of the sensitized film from the paper).

The fuming should be done only for immediate use of the paper, as it impairs the keeping qualities of the sensitized coating before fixing. Fuming is best done in a wooden box about six inches or more deep and having a wooden grating supported about three inches above the bottom of the box. A saucer containing some "stronger water of ammonia" is placed on the bottom of the box, the grating is placed in position with the albumenized paper laid flat upon it, and the box is now closed, exposing the paper for fifteen to thirty minutes to the ammonia vapor. This operation should be conducted under exclusion of light, and

it is recommended to remove the paper from the box at least five minutes before it is placed in the printing-frame.

As most prints have an unpleasant reddish tint when they leave the printing-frame they are generally subjected to the *toning process*, which converts the reddish tint into a warm sepia, a brown or a dark-purple tint, approaching a black color, according to the formula used for preparing the toning-bath and dependent on the length of time they were exposed in the printing-frame.

A. Toning Photographic Prints.

Papers requiring development of the latent image, of course need no special toning-bath, their pictures appearing under the action of the developer in soft and warm effects, either in black and gray or in black and brown tones.

There are many formulas available and many preparations in the market, both for making separate toning-solutions and "combined toning-baths," which tone and fix the print at one immersion. Nearly every brand of printing-out paper is furnished with special directions and formulas for toning, fixing, and hardening.

All toning-solutions contain besides gold (or platinum) an alkali (bichromate of soda, borax, carbonate of soda, etc.) to retard the action of the bath. The more gold the print may be made to take up, the more the gold deposit will partake of a ruby color and the more permanent becomes the picture. The final tone of the picture is conditioned by both the character and the quantity of the alkali used to neutralize the acidity of the gold solution, some alkalies (acetate of soda) giving a brown to purplish tone, while others (carbonate of soda) produce tones closely approaching a soft black in the deeper shadows of the picture. For producing good brown to black tones the following plain gold "separate toning-bath" may be prepared:

Dissolve 1.3 grammes or 20 grains chloride of gold in 570

c.c. or 20 ounces distilled water and label the bottle "Gold solution."

As this solution contains one grain of gold per ounce of liquid one may substitute one ounce of the solution in all formulas for toning-baths for every grain of gold given in the formula.

Next dissolve one ounce each of acetate of soda and carbonate of soda in twenty ounces distilled water, shake the mixture well and filter into a bottle.

To prepare the toning-bath one ounce (30 c.c.) of the "gold solution" is added to forty-eight ounces (1440 c.c.) distilled water and this solution is neutralized by gradually adding of the acetate and carbonate of soda solution till litmus paper no longer changes color when dipped into this mixture. When cold tones are desired in the picture just enough of the alkaline solution should be added that red litmus paper turns blue when dipped into the liquid. An excess of alkali, however, has a tendency to make the prints appear more toned than they really are, and such prints undergo a decided bleaching in their subsequent immersion in the fixing-bath.

Ten ounces of this toning mixture will suffice to tone about eight 5×8 prints. To tone more, either a larger quantity may be made up at once or more of the gold and alkali solutions may be added to the old bath. The latter method has the advantage that this toning solution may be used at once, whereas the freshly prepared bath should be made up about twenty-four hours before it is really wanted, the freshly prepared solution working less uniform than an older one.

Should this bath tone unevenly or should the prints come out streaky, it is advised to make the bath slightly alkaline and diluted with water. The desired tone should be produced in six to ten minutes.

The temperature of this bath should be kept rather low, not to exceed 60° F.

The toning process proper is conducted as follows:

After the final washing of the prints in running water suffi-

ciently long to remove all free silver, or in five or six changes of water, they are transferred, one at a time and face downward, to the toning-bath. The tray meanwhile should be gently rocked and the prints kept in motion by transferring the lower ones to the top singly, keeping this process up to maintain a layer of liquid between the prints and to remove at the same time any air-bubbles adhering to the film surface, thus assuring an even toning for all.

Prints first begin to tone on their surface, and if not toned sufficiently deep, they will turn a reddish brown later in the fixing-bath. If the original red color appears to have disappeared, on examining the print through transmitted light, toning may be stopped.

Prints cannot be toned dark if the printing was not carried sufficiently far, and it should always be remembered that the original tone of the print will somewhat fade in the toning- and fixing-baths. Soon after immersion in the toning-bath, of which the composition has been given, the prints will change color to a dark brown, then to purple, and finally to a soft black. As soon as the prints may have been toned to the desired shade they are to be removed to clear running water, where they may remain until enough are ready for the fixing-bath.

If no running water be available the toned prints should first be placed for about one minute in a saline bath of one ounce of chloride of sodium (common salt) to sixteen ounces of water (to stop continued action of toning), to be followed by a thorough washing in several changes of water before removing the prints to the fixing-bath.

B. Fixing Photographic Prints.

After the washing following the saline bath the prints are immersed for fifteen to twenty minutes in the fixing-bath, keeping the prints in motion, the same as described for the toning process. A good plain fixing-bath may be made up as follows:

Metric Weight.		Apothecaries' Weight.
180 grammes	Hyposulphite of soda	6 oz.
75 grammes	Alum (powdered crystals)	2.5 oz.
11 grammes	Sulphite of soda (powered crystals).	3 drachms
2000 c.c.	Distilled water	70 oz.

When all these ingredients have been dissolved, add to the solution 25 grammes (6 drachms) borax, dissolved in 300 c.c. (10 oz.) hot water.

This fixing-bath keeps indefinitely and may be made up in large quantity. It should be prepared fully a day before use.

Directly after fixing, the picture should be washed, for one hour in clear running water or in ten to fifteen changes of water, at intervals of fifteen minutes, using a large tray or tank and keeping the prints separated so the water may have full access to the film and leach out all unconverted salts. If there is a tendency toward blistering the first change of water may be made saline.

To make prints flexible and to rob them of a tendency to roll up it is recommended to immerse them in the following solution for a minute or two after removal from the final washing:

Metric Weight.		Apothecaries' Weight.
90 c.c.	Glycerine	3 oz.
120 c.c.	Alcohol	4 oz.
30 c.c.	Distilled water	1 oz.

It is advisable to drain the print well, by drawing its back over the edge of the tray, to remove as much of the surplus liquid as possible, before placing the print between blotters to dry under a light pressure.

C. Formulas for Plain Toning-baths.

For producing deep-purple or bluish-black tones in the final picture the following plain toning-bath is recommended:

Metric Weight.		Apothecaries' Weight.
65 milligrammes	Pure chloride of gold	1 grain
5 grammes	Sulphocyanide of ammonia	80 grains
315 c.c.	Distilled water	11 oz.

For toning gelatine or collodion prints with platinum in place of gold, the following bath may be given:

Metric Weight.		Apothecaries' Weight.
65 milligrammes...	Chloroplatinite of potassium......	1 grain
0.5 gramme....	Chloride of sodium (salt).........	8 grains
0.5 gramme.....	Citric acid.....................	8 grains
115 c.c..........	Distilled water.................	4 oz.

D. Combined Toning- and Fixing-baths.

When a "combined toning- and fixing-bath" is used, the prints, after removal from the printing-frame, require no previous washing before immersion.

A one-solution toning- and fixing-bath may be made up as follows:

Metric Weight.		Apothecaries' Weight.
65 milligrammes...	Pure chloride of gold............	1 grain
145 c.c..........	Distilled water..................	5 oz.
30 grammes......	Hyposulphite of soda............	1 oz.
4 grammes......	Sulphocyanide of ammonium.....	1 drachm
1 gramme.......	Acetate of lead..................	15 grains
1 gramme.......	Nitrate of lead..................	15 grains

This solution should be well shaken before use, and it is best prepared a day before wanted.

The following two-solution combined bath keeps better (in separate bottles) than the one-solution bath:

A.

Metric Weight.		Apothecaries' Weight.
30 grammes......	Hyposulphite of soda............	1 oz.
24 grammes......	Alum (powdered crystals).........	6 drachms
8 grammes......	Sugar (granulated)...............	2 drachms
300 c.c...........	Distilled water (cold)............	10 oz.

After these chemicals have all been dissolved in the cold water, 15 grammes (4 drachms) borax dissolved in 60 c.c. (2 oz.) hot water are added and the mixture is well shaken. After allow-

ing it to stand for twelve hours the clear liquid may be siphoned into a bottle marked "Solution A" or "Fixing-solution."

The stock solution for toning is made by dissolving chloride of gold and sugar of lead in water.

B.

Metric Weight.		Apothecaries' Weight.
65 milligrammes....	Pure chloride of gold............	1 grain
0.5 gramme......	Acetate of lead..................	8 grains
30 c.c.............	Distilled water..................	1 oz.

This "gold solution" should be well shaken, but not filtered, before use.

For the "combined toning- and fixing-bath" mix in the proportion of one part "gold solution" (sol. B) to eight parts "fixing-solution" (solution A).

Half an ounce of stock solution B ("gold solution") mixed with four ounces of stock solution A ("fixing-solution") will tone about one dozen 5×8 prints.

The double salt "chloride of gold and sodium," which is a mixture of chloride of gold and chloride of sodium, can be more easily handled than the pure chloride of gold in making the toning-solution, since it contains no free acid. If this crystallizable double salt be used in place of the pure chloride of gold in preparing the "gold solution" of a toning-bath, double the quantity will be required of the amount given for the pure chloride of gold in the preceding formulas.

After the desired tone has been attained for the prints in the combined bath they should be removed to a saline solution (1 teaspoonful of salt to sixteen ounces water) and immersed five minutes, after which they are washed in ten to twelve changes of water at intervals of fifteen minutes.

To insure *thorough* fixing the prints may be immersed for ten minutes in the fixing-bath previously given, or in the following one, immediately after the first change of water following the saline bath.

Metric Weight.		Apothecaries' Weight.
240 grammes......	Hyposulphite of soda..........	8 oz.
30 grammes......	Sulphite of soda (granulated, dry)..	1 oz.
3.5 c.c..........	Sulphuric acid..................	1 drachm
960 c.c...........	Distilled water..................	32 oz.

After removal from this bath the prints should be thoroughly washed in clear running water for at least one hour or in ten to fifteen changes of water as previously noted. If the prints be now immersed in the following bath for five minutes any remaining trace of "hypo" will be removed and the film will become hard when dried:

Metric Weight.		Apothecaries Weight.
960 c.c...........	Distilled water..................	32 oz.
30 grammes......	Powdered alum..................	1 oz.
30 grammes......	Powdered chloride of sodium (salt).	1 oz.

After removal from this "hardener and short stop" the prints are again washed and dried.

Combined baths should be used but once and they should be kept at a rather low temperature, not much over 50° F.; if the temperature is allowed to rise much above this the prints will become stained yellow and the darker tones will be tinged with a greenish tint. Prints should not be retained in the water over two hours. All trays should be kept scrupulously clean and not interchanged. Whenever prints come out "splotchy" it is recommended to clean the trays, swabbing them out with diluted sulphuric acid.

Those who prefer to "cut" their own gold for the "toning-solution" can make up a stock solution of the "gold solution B" in the above combined bath as follows:

Metric Weight.		Apothecaries' Weight.
156 centigrammes..	Pure metallic gold..............	24 grains
3.5 c.c..........	Nitric acid......................	1 drachm
10.5 c.c..........	Muriatic acid....................	3 drachms

After the gold has been fully dissolved, add 1440 c.c. (48 ounces) distilled water and then add enough bicarbonate of soda to leave the solution slightly acid, just enough to turn blue litmus paper red. After shaking well filter into a bottle, add 25 grammes (384 grains) acetate of lead, and label this stock solution "Gold solution," or "Solution B" of the combined bath.

CHAPTER XII.

CONCLUSION AND REMARKS ON THE PRECISION OF THE "POLAR-ICONOMETRIC" METHOD AND GENERAL REMARKS ON TELEPHOTOGRAPHY.

I. General Remarks on Phototopography.

THE main disadvantage in connection with phototopography, resting principally in the great consumption of time in the production of the maps in the office, promises soon to be overcome through the perfections that are being made in the stereoscopic methods and instruments. The plotting of from fifteen to thirty control points, by means of the "polar-iconometric" method (by the intersections of at least three radials or horizontal directions for each control point), including the plotting (or the "orientation") of the necessary picture traces, together with the verification of the focal lengths of the photographs, may be regarded as a good day's work.

The main advantage in phototopography, on the other hand, rests in the rapidity with which the field work may be done. The phototopographer, spending most of his time in traversing the country, stopping only long enough at the stations to photograph the panorama, to make sketches, and to observe a few sets of angles with the transit, can in a few good days cover a larger territory than is possible with any other surveying method.

A phototopographic party is essentially an economic one, inasmuch as it comprises but one topographer, assisted by as many packers or hands as may be needed to transport the party outfit over the region that is to be surveyed. The time-con-

suming part of the work (the iconometric plotting) is independent of weather conditions and may be accomplished at any time by one or two iconometric draughtsmen in the office.

The ready identification of points on the photographs is a matter of practice and will be found far less difficult than would appear at a first attempt. All apparent difficulties in this respect may soon be overcome by a comparative study of several pictures held side by side, and also by making use of the numerous tests and constuctions that are available for this purpose, the most important of which having been given under Prof. G. Hauck's method. We have also seen that this difficulty disappears altogether when applying the stereophotographic methods.

To economize in time, the general progress of the field work should, as far as possible, be regulated by the weather and climatic conditions of the region to be surveyed. Elevated stations should be occupied during good weather, as the lower stations, being more readily accessible and less often obscured by clouds, may be successfully occupied at almost any time. Good work may often be done at the lower stations when work on the mountain peaks is impossible, owing to misty weather, snow, or strong winds prevailing here, while the lower altitudes may be free from either during the same time period.

Special attention should be given to a good selection of the camera stations, with reference to the elevations and the distances of the terrene points that are to be determined, to the focal length of the camera, the desirable degree of accuracy, the scale of the map, and the general character of the country. A diversified and broken terrene will require more stations to obtain a good topographic development and representation on the map than a more regular section; the camera stations, however, should be selected to obtain a full control of all depressions, valleys, and general topographic features from the smallest number of camera stations. Every feature that is to find a representation on the map should have been photographed from at least two, better three, stations. If a

part of the terrene be visible from two stations only its iconometric location in horizontal plan may be accepted if its control points on the plan have been determined by good intersections (if the horizontal lines of direction intersect each other at angles of 40 to 90 degrees), otherwise "vertical" intersections or other means for checking the location of these points will have to be adopted unless additional stations may be occupied, while the party is still in the field, to obtain lines for a third intersection.

On the other hand, to reduce the number of photographic plates that are to be transported, to simplify the iconometric office work, and with due regard to the limited length of the working-season in mountainous regions, it will be advisable not to occupy more stations than are actually required for the proper development of the terrene.

To secure the proper control for the location of the camera stations on the map, at least three, better four, lines of direction to surrounding geodetic (triangulation) points should be observed from each camera station. If that many triangulation points be not visible from the station, that number of directions should be observed anyway, pointing on other well-defined points (to supply the deficiency in triangulation points) that may have been located before (as other camera stations), or which may be located by later observations to be made at stations still to be occupied. Every station should be marked with a signal before leaving, and such signal is to be observed upon from stations subsequently occupied, observing both horizontal and vertical angles.

Regarding the selection of the hours that are most favorable for photographing the panorama views, one should be guided principally by local conditions. Generally speaking, views of identical regions should, if possible, be taken at the same time of day and under similar atmospheric conditions, to facilitate the recognition of identical points on the different views; the actual shadows will then be alike in the different pictures. Pho-

tographing slopes altogether in shadow and exposing plates when the sun is low should be avoided as far as possible. In the latter case additional trouble may arise from the fact that one or more pictures taken in the direction toward the sun may be affected by halation; they will at best be more or less flat and will always be deficient in details. Still, the phototopographer is seldom privileged to select the most favorable time for making the exposures, being governed by many considerations, having but a limited time at his disposal, having to contend with moving cloud-masses, inaccessibility of points, etc. Sometimes views will have to be taken toward the sun if they are not to be dispensed with altogether, but with the exercise of care and judgment photographs may be obtained that will be of value for the iconometric plotting, even when taken under such adverse conditions. The camera-lens, however, should always be carefully shaded when taking pictures under such untoward conditions.

It may generally be stated that the best results in mountainous countries are obtained when the plates are exposed in the latter part of the forenoon, the elevated peaks being mostly "hooded" in clouds during the afternoon. Although these clouds frequently disappear again late in the afternoon or toward evening, still at this late hour all details of the valleys are obscured if not perfectly hidden in a misty darkness.

When everything is favorable, the entire work at a camera station may be finished within an hour and a half, or two hours at the longest, and as three well-placed stations will control the horizontal and vertical representation of an extended area, a large territory may be reconnoitered phototopographically in a comparatively short time.

The time consumption for accomplishing the *field work* of a detailed phototopographic survey will be about the same as for a more generalized survey, as about the same number of photographs will be required in both cases. The difference, however, appears at once during the execution of the *office work.* In the first case the number of points to be plotted iconometrically

may be very large, while in the latter case it will naturally be very small, comprising points which characterize and control the main features and forms of the terrene only.

We find, therefore, that outside of topographic reconnaissance surveys in mountainous districts the phototopographic methods are particularly well adapted for executing topographic preliminary surveys made for that class of engineering works in which the final and best location of the enterprise depends upon a comparative study of the different sites as represented on the topographic maps. Only a limited number of points would have to be determined iconometrically to reach a decision whether the site under consideration fulfills the required conditions. After the best site has been determined upon, a more detailed and accurate map may be constructed from the same field data without having to supplement the original survey, either by additional observations or photographs, every panorama view giving the means to plot therefrom (iconometrically) almost an unlimited number of terrene points.

II. Precision of the "Polar-iconometric" Method.

The desired degree of accuracy in a survey will generally determine the class of instruments and the methods to be used in its execution. To ascribe, therefore, the various surveying-cameras and phototheodolites their proper places among surveying-instruments, it will be of importance to know, or to ascertain, what degree of precision may be obtainable with each representative type of a special class. This has been done for some of the special types that have been described in the preceding chapters, and we will here enter upon a more general consideration of the precision attainable in the so-called "polar" or "radial" method of iconometric plotting.

We have seen that the graphic methods of phototopography

are very similar to those of the plane table. It is generally accepted that azimuthal errors in the directions of the " radials," drawn with the plane-table alidade on the plane-table sheet, should not exceed 1.5 minutes in arc, and we shall see that when the principal focal length of the camera does not fall below 150 mm. this same degree of accuracy in the angular values of the lines of direction may be obtained iconometrically from the panorama views.

The plotting from photographic perspectives being dependent on the measurements of coordinates made directly on the photographic perspectives, the attainable degree of accuracy will greatly depend both upon a good definition and upon the mathematically correct representation in perspective of the landscape upon the flat field of the perspective (negative).

The precision in the mechanical determination of the coordinates of any point pictured in the photographic perspective depends not only upon the more or less good definition of the pictured point, but also upon the means used for measuring these coordinates. According to Dr. Meydenbaur, the definition of a photograph obtained with a suitable lens will be sufficiently good for phototopographic purposes if a point, or rather its " phase," or the circle of diffused light that represents the point on the picture, does not exceed 0.1 mm. in diameter; hence all pictured lengths should be obtainable within a limit of $dx = dy \leqq 0.1$ mm. Unless special measuring devices are employed, this value will also represent the attainable degree of accuracy in making direct measurements on clear and well-defined negatives with ordinary drawing instruments (dividers and transverse scale). It is evident from the foregoing that a computation carried out to several places of decimals (analytic method) cannot increase the accuracy of the resulting map as long as the elements of the perspectives upon which such computations are based have been obtained with a degree of accuracy not closer than 0.1 mm. All iconometric plotting being dependent on direct measurements executed on the photographic plates,

the transcription of the pictured data into the horizontal projection plane is best done graphically.

Numerous experiments have shown that 0.14 mm. is the smallest discernible difference in length that the average eye may distinguish without optical aids. With a beveled scale graduated to 0.5 mm. a fairly well-trained eye can determine lengths correctly within 0.1 mm., while a well-trained eye reaches the limit at 0.06 mm. By the use of special scales fitted with verniers and microscopes the attainable degree of accuracy in the measured lengths may be increased to reach 0.03 mm.

The attainable degree of precision in the angles may be found from the equations

$$\tan\alpha=\frac{x}{D} \text{ (for horizontal angles)},$$

$$\tan\beta=\frac{y}{\sqrt{D^2+x^2}} \text{ (for vertical angles)},$$

where x = abscissa of the pictured point;
y = ordinate of the pictured point;
D = distance line of the perspective.

By differentiation we find

$$d\tan\alpha=\frac{1}{D}dx,$$

$$d\tan\beta=\frac{dy}{\sqrt{D^2+x^2}}-\frac{x\cdot y}{\sqrt{D^2+x^2}}dx.$$

If we express x by an aliquot part of D, $x=\frac{D}{n}$, and disregard $\left(\frac{x}{D}\right)^2=\frac{1}{n^2}$, and introduce the arcs in place of the tangents of the

angles, we will find

$$d\alpha \text{ (in seconds of arc)} = 206265\frac{dx}{D};$$

$$d\beta \text{ (in seconds of arc)} = 206265\frac{dy}{D}.$$

These equations show that the angular errors are directly proportional to the degree of accuracy attainable in the measured lengths (on the photographs) and indirectly proportional to the focal lengths of the lenses that are used. Assuming the attainable degree of accuracy in the measured lengths to be $dx = dy = 0.1$ mm., we will find the attainable degree of accuracy for the angles for the following five focal lengths to be:

For a	focal	length	=20 cm.	the	angular	accuracy	is	1′	43″
"	"	"	=25	"	"	"	"	1′	25″
"	"	"	=30	"	"	"	"	1′	09″
"	"	"	=35	"	"	"	"	0′	59″
"	"	"	=40	"	"	"	"	0′	52″

The longer the focal length of the lens the smaller the angular error will be, and although it is desirable to have the photographic details as large as possible for a better identification of the terrene points on different photographs and to increase the attainable degree of accuracy, still, to reduce the weight of the instrument as much as possible the focal length will naturally be circumscribed for instruments to be used in mountainous regions, where portability and compactness are among the prime factors to be considered in their construction.

The attainable degree of accuracy for any particular camera may be ascertained experimentally, after the methods of Dr. W. Jordan and Capt. E. Deville, by observing a series of horizontal and vertical angles, included between lines of directions, to a series of well-defined points of known positions and elevations,

taking also a photograph of the same points (in vertical plane) from the same station and from the same elevation. The horizontal optical axis of the camera should have the same height as the horizontal optical axis of the transit telescope when the angles were measured, or the difference in the elevation between both should be taken into account.

The focal length of the photographic perspective and the correct positions of its horizon line and principal point may now be determined from the requisite number of observed directions to the known and plotted points. The remaining angles, measured in excess of the required number just referred to, may well be used for comparison with the corresponding values, obtained iconometrically from the oriented picture trace, to arrive at a knowledge of the attainable degree of accuracy of the camera in question.

If the camera-lens was of good quality (for surveying purposes), if the selected points were well defined (both in nature and on the negative), if the sensitized surface of the plate contained no gross inequalities or irregularities, and finally, if the measurements of the coordinates were carefully made on the negative, the lengths obtained iconometrically on the plotting-sheet, compared with those obtained trigonometrically, should differ by no more than 0.1 mm. in actual length, and the iconometric angles should differ from those that were observed by no more than from 1 to 2 minutes in arc for objectives with focal lengths from 350 to 150 mm. and commanding a horizontal field of view from 50 to 60 degrees.

This degree of precision may be increased by a reduction in the field of view of the lens by using plate glass for the negatives and by making microscopical measurements of the coordinates of the pictured points. Still, when photography is applied in this way, including precise computations (analytic method), for surveying purposes, one of its main advantages is lost sight of and sacrificed, since one of the chief advantages in phototopography rests in the numerous and varied constructions (based

on the laws of perspective) that are available in transferring the photographically recorded data to the plotting-sheet.

The attainable degree of accuracy in the elevations obtained iconometrically may also be ascertained in the manner indicated, but the results will only hold good for points having the same distances as those observed upon with the transit from the camera station.

To find the limit in the distances that are to be included for a certain lens when a given degree of accuracy in the elevations is to be maintained, we may proceed in the following manner:

We have the known relation

$$\frac{1}{a}+\frac{1}{b}=\frac{1}{f},$$

or

$$\frac{b}{a}=\frac{f}{a-f}; \quad b=\frac{a\cdot f}{a-f};$$

where a=distance between object and second nodal point of the lens;

b=distance between image and second nodal plane of the lens;

f=constant focal length of the camera-lens.

We had seen that the elevation (B) of any pictured point above the horizon line stands in the same relation to the eletion (A) of the point itself, above the horizontal plane that passes through the horizon line, as the horizontal distance (b) between lens and image is to the horizontal distance (a) between the lens and the horizontal projection of the point itself.

$$B:A=b:a,$$

or

$$\frac{B}{A}=\frac{f}{a-f}.$$

In topographic surveys the distance a will be so great compared with f that the latter may be neglected in comparison with a, and we will have, with close approximation,

$$\frac{B}{A}=\frac{f}{a}, \quad \text{or } a \text{ (approx.)}=\frac{A \cdot f}{B}.$$

Hence, whenever the considered distances a are large compared with the focal length, we may place $b=f$, which means that the phototopographic cameras may be constructed with constant focal lengths, which in point of fact is the general practice.

If differences in the elevations of points of the terrene are to be deduced photogrammetrically within a limit of error not exceeding one meter, the pictured length (B) of a meter in nature (A) should not appear shorter than 0.1 mm., and we find for the following four typical values of focal lengths the corresponding values for a, representing the extreme distance limit between the camera station and an object one meter high that is to have a pictured height of at least 0.1 mm. as follows:

	$a=$ 750 m.	1000 m.	2000 m.	2500 m.
for	$f=$ 75 mm.	100 mm.	200 mm.	250 mm.

It would require the exercise of special care and the measurements of the coordinates would have to be made directly on the negatives if this limit of error is to be maintained. Carefully made contact prints permit measurements to be taken (with the ordinary instruments of the draughtsman) correctly, with an average error of not less than 0.25 mm., and taking this limit as commensurate with good work, we will now have:

	$a=$ 300 m.	400 m.	800 m.	1000 m.
for	$f=$ 75 mm.	100 mm.	200 mm.	250 mm.

These values clearly demonstrate the necessity for a close disposition of the camera stations over the area to be surveyed

(from 600 to 2000 m. apart) for detailed work, thus materially circumscribing the advantages of phototopography, practically excluding its application to the topographic surveys of rugged mountains, a terrene for which the phototopographic methods are best suited and to which, as a matter of fact, they have primarily been applied with the greatest success as long as larger errors (exceeding one meter) in the elevations were permissible. Thus, if the error in the iconometrically determined elevations may attain twenty meters, and if the coordinate measures may be correctly obtained on the prints within an error of 0.25 mm., we will find the following values for the effective range for the same four focal lengths to be:

	$a=$ 6000 m.	8000 m.	16000 m.	20000 m.
for	$f=$ 75 mm.	100 mm.	200 mm.	250 mm.

For a permissible error in the elevations of twenty meters the camera stations may be located at intervals of from 10,000 to 40,000 meters, for cameras with focal lengths from 75 to 250 mm., provided the character of the terrene does not require a closer disposition of the stations to obtain a better development of the intervening terrene forms.

Attempts have been made to increase the effective range of the surveying-cameras by constructing them with variable or adjustable focal lengths; this, however, produces complications and opens additional sources of error. Better success in this direction has been obtained indirectly by using photographic enlargements ("optical projections") of the original negatives in the iconometric plotting. This method is successfully pursued in Canada under Capt. E. Deville, Surveyor-general of Dominion Lands, who advises the use of enlarged positives on glass for work requiring a high degree of accuracy.

If the reconnaissance of a given terrene has established the greatest limit between the camera stations to be $2a$, we can,

for a required degree of accuracy, find the proper focal length of the camera from the equation

$$f=\frac{B}{A}a.$$

The accuracy attainable in iconometric plotting depends greatly upon the distances between the several camera stations. We had seen that the precision of a plotted line of direction depends upon the accuracy with which the abscissa x may be transferred from the photographic perspective to the plotted picture trace. The camera station being fixed, the accuracy in the direction of the ray will depend solely upon the value or the amount of the error dx with which the measured abscissa x may be affected. With a given limit dx for a constant focal length f, the error in position of a plotted point will increase with the distance of the latter from the camera station. All plotted points falling between the picture trace and the plotted camera station are affected by no errors larger than dx, and if the permissible limit of error in the map is not to exceed dx, we will have to select the camera stations sufficiently close together that no points are determined iconometrically which fall beyond the traces of the pictures from stations whence the latter were obtained. The base-line lengths are plotted to scale, while the constant focal length of the camera enters into the iconometric construction in its original length; hence the reduced lengths separating successive camera stations on the plan should not surpass the true focal length f. For a scale of map of $1/n$ the largest base line should be $\leqq f \cdot n$, measured in millimeters. For a focal length of $f=200$ mm. and a scale of map of $1/20000$ the base line should not exceed 200×20000 mm. or 4000 meters, measured in the plotting-scale.

All elevations determined from the photographs should be corrected for curvature and refraction. Refraction apparently affects directions more in the vertical than in the horizontal

sense. Prof. S. Finsterwalder found in his phototopographic surveys made in 1888 and 1889 that the accuracy in the *elevations* increases directly with the distance of the observed point. The elevation of a point 500 m. or less distant from the camera station was three times less accurately obtainable, iconometrically, than the elevations of points between 2500 to 5000 m. distant.

Generally speaking, terrene points determined iconometrically will not be provided with signals, and the identification of a well-defined point on several photographs may be affected by an error of from one to two minutes in arc. Even points that may have been supplied with signal poles of the ordinary size and length, when five hundred meters and more distant from the camera stations, will appear on the photographs as having no signals, yet when viewed through the telescope of the ordinary field transit, the same poles may appear very clearly and well defined, even at distances up to several kilometers. Artificial signals will, therefore, be of little use in general iconometric plotting; still, as well-defined points are a necessity to insure good results, the camera stations should be located not too far apart, and the selected reference points of the pictures should not only be sharply defined, but the instrumental measurements to the same objects (to provide the needed data for the orientation of the picture traces and for the control) should be made as nearly as possible at the time of the exposure of the plates, that such points may be seen under the same conditions of illumination that prevailed when they were photographed.

Regarding the expeditiousness of the phototopograghic methods considered in the preceding chapters, it may be stated, from the experience of Dr. S. Finsterwalder, that so-called topographic surveys of mountain regions, for which an artistic representation of the terrene, in conformity to its natural appearance, may be claimed rather than accuracy, may be made by an expert plane-tabler, combining liberal sketching with the instrumental survey, on 1/25000 scale in less time than it would

take the phototopographer to select, locate, and occupy the camera stations required for an "accurate" phototopographic survey to be plotted on 1/10000 scale. This holds good for surveys in mountains of an Alpine character and sparse vegetation.

Besides the errors considered in the preceding paragraphs, there still remains another source of error to be considered in the photographic developing and fixing process of both the negatives and their positives. Distortion in the sensitized gelatine coating of the modern dry-plate during the process of development is rarely perceptible if the work is carefully done to avoid so-called "frilling" of the film. The mean value of such distortion, according to Dr. H. C. Vogel, amounts to 0.01 per centum of the length, and as the plates used in phototopography are never large, the errors due to this cause may be disregarded altogether.

The distortion in the positives (particularly if made on paper that requires subsequent development), however, is mostly so large that it must be considered when using such prints iconometrically. This distortion, moreover, is irregular, being smaller in the direction with the grain or fibers of the paper, where it may amount to 0.5 per centum of the length, and larger in the direction across the fibers, where it will amount to about 1 per centum. The constants of the camera, therefore, and the coordinates of the principal points of control should preferably be obtained from the negatives. For the iconometric plotting of the topographic details enlarged projections on bromide paper may be used. Capt. Deville has recently substituted a heavily coated "platino-bromide" paper for the ordinary silver bromide paper heretofore in use. The length of exposure for the enlargement is made directly dependent upon the density of the original negative.

To give ready means for controlling or correcting the distortion affecting the paper prints nearly all modern surveying-cameras are provided with a metal frame permanently fixed in the image plane of the lens with constant focal length, the inner

margins of the frame having a graduation that is photographically reproduced on the outer margins of the negative; thus the amount of distortion that may affect the positive can readily be ascertained in the directions of both the horizon and the principal line of the photographic perspective. "Backing" the paper prints would open another source of error even greater than those just referred to. Dr. Stolze observed a permanent expansion of five per centum for prints that had been mounted while in a damp condition.

III. General Remarks on Telephotography or Long-distance Photography.

The range in the field of application of photography to surveying and military reconnaissance has been considerably enlarged during the past few years by the invention of the telephoto-lens combination, used for obtaining well-defined photographic views of objects at long distances, sacrificing or reducing the angular value that the plain lens commands for the sake of enlargement of the view, producing thereby the same effect as if the view had been taken from a point of view much nearer to the distant object.

Long-distance photography ("telephotography") was probably first studied in France, principally by Matthieu and Lacombe, and more recently by Guillemont and Jarret. This subject continues to receive much attention in France, particularly among the army officers stationed at Grenoble, as has been mentioned in Chapter I. Quite recently telephoto instruments have been devised and placed upon the general market by Hondaide and Derogy in Paris. The lunette d'État-Major, one of the smaller types of telephoto instruments, manufactured by Arizard in Paris, controls distances up to 5 km. and weighs only about 8 kg.

The Intelligence Office of the British War Department is also doing a great deal towards promoting the efficiency of the

telephoto instruments and towards familiarizing British officers with the telephotographic reconnaissance methods. The invention of the telephotographic lens combination is ascribed by Th. R. Dallmeyer to Peter Barlow, who combined a negative lens with the astronomical telescope as early as 1834.

Researches in long-distance photography have notably been made by T. R. Dallmeyer, London; Dr. A. Miethe, Potsdam; Dr. Steinheil, Munich; Prof. R. Spitaler, Vienna, and others.

One of the main defects in phototopography rests in the small scale to which the distant landscape features are reduced on the negative, requiring precise and minute measurements to be made on the negative in connection with the iconometric constructions. This defect is primarily conditioned by reducing the weight of the surveying-cameras to a minimum. Cameras with constant focal lengths are principally in use for topographic surveys in mountainous regions, where the reduction in weight, as previously stated, means a great deal toward ultimate success. For this class of work the use of objectives of long focal lengths is precluded and we find topographic-surveying cameras supplied with lenses having constant focal lengths from 75 to 350 mm.

In the preceding chapter the effective ranges of four-lens types have been discussed, fully demonstrating the desirability of providing means for obtaining special perspective views of terrene sections lying beyond the reach of the ordinary camera-lens, for certain inaccessible localities and particularly for military reconnoitering purposes.

By adding the so-called telephoto attachment to the original camera-lens an enlarged image of the view is photographed directly on the plate (in the field). The use of the telephoto attachment (it may easily be removed) has the advantage that the selection of the distant views rests entirely with the topographer in the field, as he can best decide whether by taking such a telephotographic view from one of the ordinary camera stations a lengthy trip of the party in that direction may be saved,

or whether a special advantage may be derived from a series of such views taken during the occupation of some prominent or isolated peak. In short, the phototopographer can best tell whether time may be saved by supplementing the ordinary panorama views with some special long-distance views.

In high altitudes mists and clouds frequently hide the higher peaks from view for weeks at a time, and it may often save many days of waiting if the phototopographer be provided with a telephoto attachment for his camera-lens, to enable him to photograph distant terrene features that may casually be visible on a clear day while taking the panorama views for the development of the topography in the immediate neighborhood of the station.

The topographer may not see the same peaks free from "cloud-hoods" again during the rest of the season, at least not from that particular direction. It will seldom require more than one such telephoto view in several panorama sets, the critical points pictured on the other plates being near enough to the station not to need special enlarging.

Little regarding the telephotographic results, obtained principally under military auspices, reached the general public until Dr. A. Miethe, in Germany, and T. R. Dallmeyer, in England, each apparently independent of the other, published descriptions of their telephoto-lens combinations. The principal difference between their combinations seems to be that Dallmeyer uses a "portrait-lens" in connection with the "negative-lens combination," while Dr. Miethe combines a photographic lens of the "rapid landscape type" (Steinheil's) with the negative combination. The construction of both these telephoto objectives rests upon the same principles, and their combination is composed of two biconvex lenses interposed between the camera-lens and the sensitive plate. By changing the distance between the biconvex lenses more or less enlarged images will be photographed on the plate. These enlargements are made at a sacrifice of the field of view commanded

by the camera-lens alone, and it would require a large number of plates to cover the entire horizon with telephoto views; still, in phototopography the general panorama views will be taken with the simple camera-lens, adding the telephoto attachment only for special views of distant "heads," or saddles of valleys, inacessible mountain peaks, etc.

Since the "negative element" of the telephoto combination lens produces a picture of the distant view in the image plane of the camera with a sharp definition and a richness in detail far surpassing the perceptive power of the eye, and, on the other hand, the wide angle type of camera-lens (the "positive element") reproduces, with an evenly good definition, views subtending angles far surpassing the field of view of the eye, it will be plain that the combination of these two elements into one optical system will give results that cannot be obtained in any other manner. The telephoto combination works particularly well for picturing objects that are about equidistant from the lens (for picturing objects that are in the same frontal plane), but when objects are photographed that are at different distances from the instrument the image will be more or less distorted by the effects of spherical aberration. This spherical aberration may be reduced in a measure by stopping down the camera-lens; this, of course, decreases the intensity of the illumination of the image, reduces the rapidity of both the lens and the plate, contracts the already small field subtended by the telephoto combination, and consequently necessitates an increase in the time of exposure, with the incident risk of communicating tremors to the camera which would be detrimental to the definition of details in the telephoto-plate.

Dallmeyer recommends, therefore, for a "really useful telephotographic lens system" the combination of the rapid rectilinear type of lens $\left(\frac{F}{8} \text{ or } \frac{F}{7}\right)$, together with a negative lens of half its focus. In this proportion the latter may be made of larger diameter than the lenses of the positive element, thereby

increasing both the included angle and the illumination of the plate, as when using a negative lens of smaller diameter than that of the positive element. With observance of this recommended proportion of the foci the negative element (attached to the positive lens) will not become inconveniently large and heavy. Negative lenses with foci a little longer than half the focus of the positive set may safely be used to increase the field of view (the included angle) at a reduction in the magnification of the image.

When using a telephoto-lens the instrument should be well and rigidly supported, as the smallest tremors of the camera become magnified in their effect upon the image and probably would spoil the plate for phototopographic purposes. The focusing should be very carefully made, using the same stop that is to be used for the subsequent exposure. Generally speaking, the best results will be obtained on a calm day after a rain or when the atmosphere is perfectly free from smoke and dust. To obtain good results for distant mountain views, of course a yellow color-screen or ray-filter will have to be provided. It is also of great importance that the photographic plate be in perfect contact with the metal frame of the camera, as even a slight irregularity in this respect would spoil the negative for iconometric purposes.

Telephotographic cameras combined with phototopographic methods no doubt will play an important part in modern wars and maneuvers where smokeless powder will be in general use, to reveal the positions of hostile troops and enable the observing officers to obtain a correct idea of the positions of the enemy, and consequently of his plans (inasmuch as these may be deduced from the recognized disposition of the forces in the field). Light transportable "conning towers" supplied with "telescoping" or extension tubes and prism reflectors will probably form the most satisfactory support for the telephoto-lens combination when used for strategic reconnoitering purposes. For use in the army a telescoping-tube system could

be devised to serve in place of the center pole of the dark-tent.

The following are some of the better-known publications on long-distance photography and telephoto-lens attachments:

T. R. DALLMEYER. "The Telephotographic Lens," published by J. H. Dallmeyer. London, 1892.

T. R. DALLMEYER, F.R.A.S., etc. "Telephotography: an Elementary Treatise on the Construction and Application of the Telephotographic Lens." London, 1899.

M. le capitaine du Génie BOUTTREAUX. "Mémoire sur la téléphotographie." Nro. de Sept., 1897, Revue du Génie.

Mémoire du chef de bataillon Allotte de la FUYE, commandant l'Ecole du Génie de Grenoble. "Sur l'Emploi des appareils photographiques pour les observations à grande et à petite distances." Autographié à l'Ecole du Génie de Grenoble, 1891.

AUG. VAUTIER-DUFOUR. "Sur la Téléphotographie." Bulletin de la Société Vaudoise des Sciences naturelles, No. 143. Lausanne, 1902.

NICODEMO JADANZA. "Il Teleobbietivo e la sua Storia." Torino, Carlo Clausen, 1899, Estratto dalle Memorie della Academia delle Scienze di Torino, Serie II, T. XLIX.

MAX LOEHR, Chef de la maison C. A. Steinheil, Paris. "Du Téléobjectif." Annexe du bulletin de la Société française de Photographie, 1902.

MAX LOEHR. "Sur la Détermination des Mésures du Téléobjectif." Bulletin de la Société française de Photographie, 1902.

Dr. P. RUDOLPH. "Anleitung zum Gebrauch des Teleobjectifs von der Firma Carl Zeiss." Jena, 1896.

C. A. STEINHEIL. "Ueber Fernphotographie." Phot. Correspondenz, 1892.

Dr. A. MIETHE. "Photographische Optik."

LECHNER'S Mittheilungen, Feb. 1892.

Mittheilungen aus dem Gebiete des Seewesens, 1894.

Revue du Cercle Militaire, 1895.

The American Annual of Photography, 1896.

Zeitschrift fuer Vermessungswesen, 1892.

ANTHONY'S Photographic Bulletin, 1892 to 1894, etc.

INDEX.

A.

C.

D.

E.

I.

J.

K.

L.

M.

N.

O.

P.

U.

V.

W.

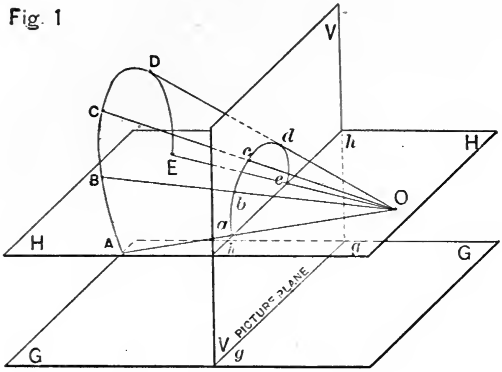
Y.

Z.

PLATES.

PLATE I

Fig. 1



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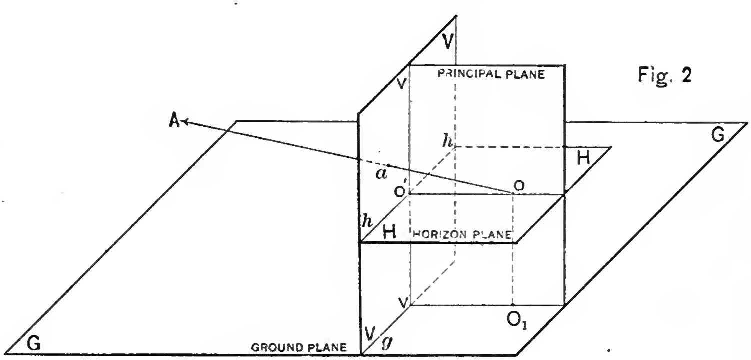

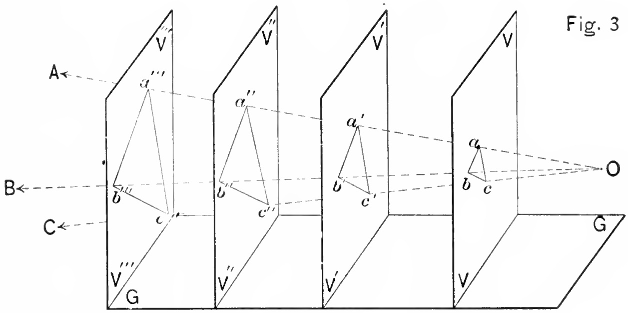
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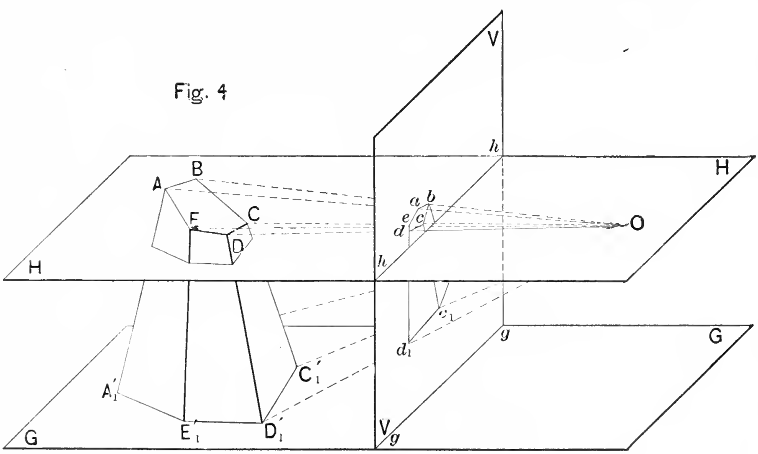
V''
V'
V
A
a'''
a''
a'
a
O
B
b'''
b''
b'
b
c
C
c'''
c''
c'
G
V'''
V''
V'
V
G

Fig. 3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h
H
B
A
a
b
F
C
e
c
d
O
D
H
h
c₁
g
G
d₁
C'₁
A'₁
E'₁
D'₁
G
V
g

Fig. 4

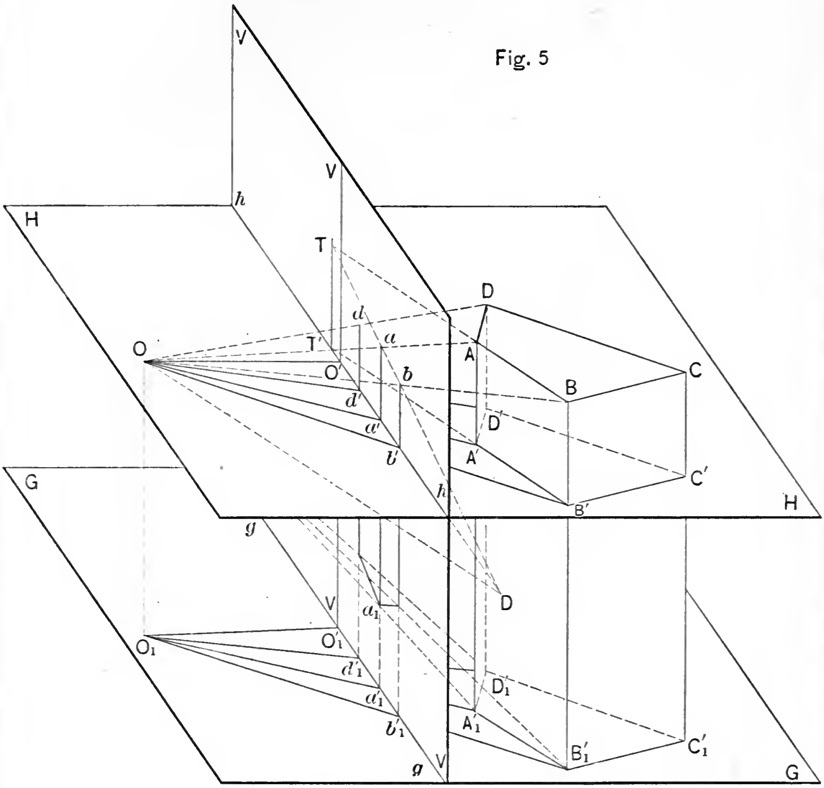
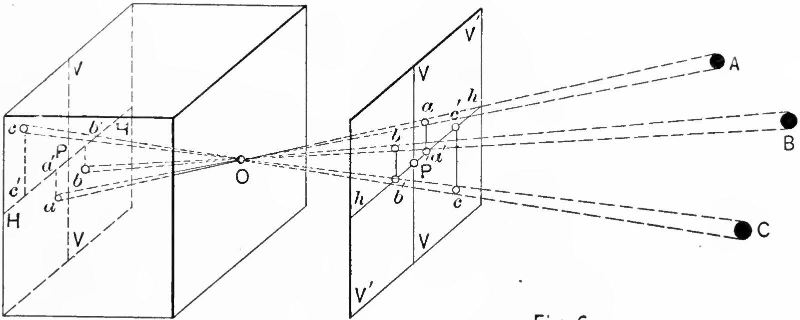

V
V
h
H
T
D
d
a
T'
A
O
O'
b
B
C
d'
D'
a'
A'
b'
C'
h
B'
H
G
g
D
V
a_1
O_1
O'_1
d'_1
D'_1
a'_1
A'_1
b'_1
B'_1
C'_1
g
V
G

Fig. 5



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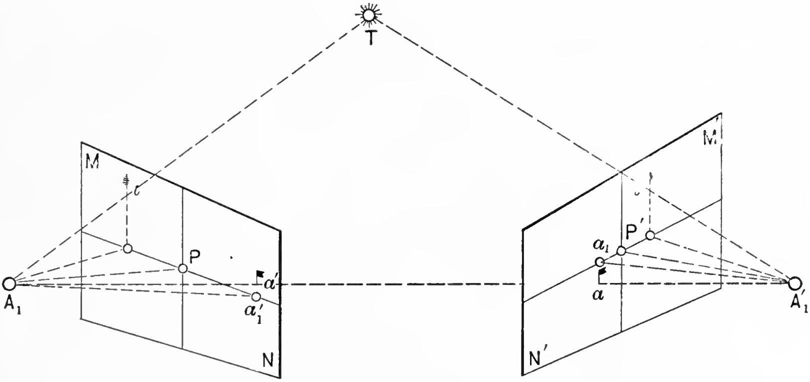

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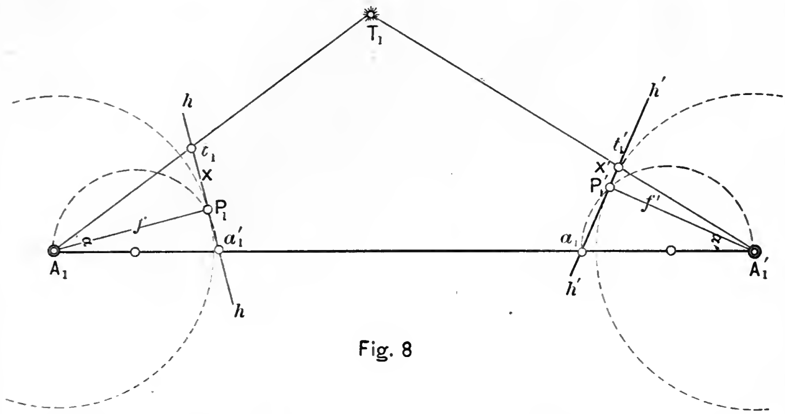

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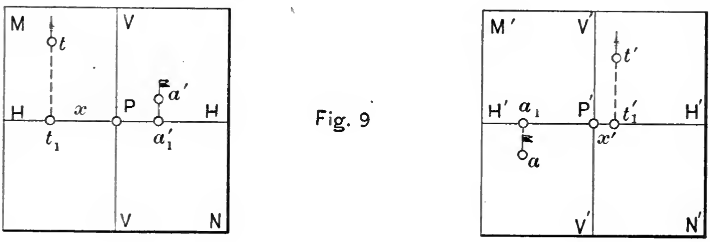

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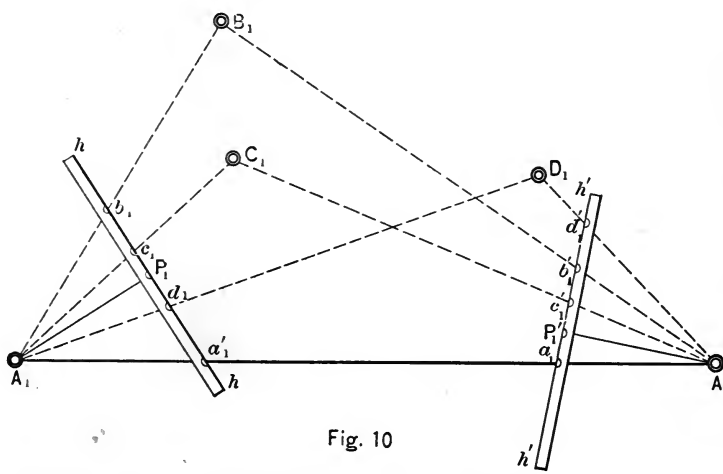


Fig. 10

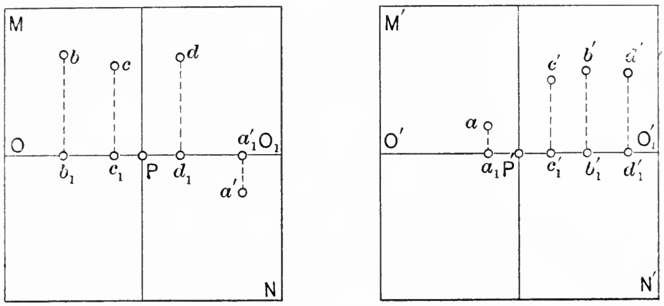

M
b
c
d
O
a'₁ O₁
b₁
c₁
P
d₁
a'
N
M'
c'
b'
a'
a
O'
O'₁
a₁ P'
c'₁
b'₁
d'₁
N'

Fig. 11

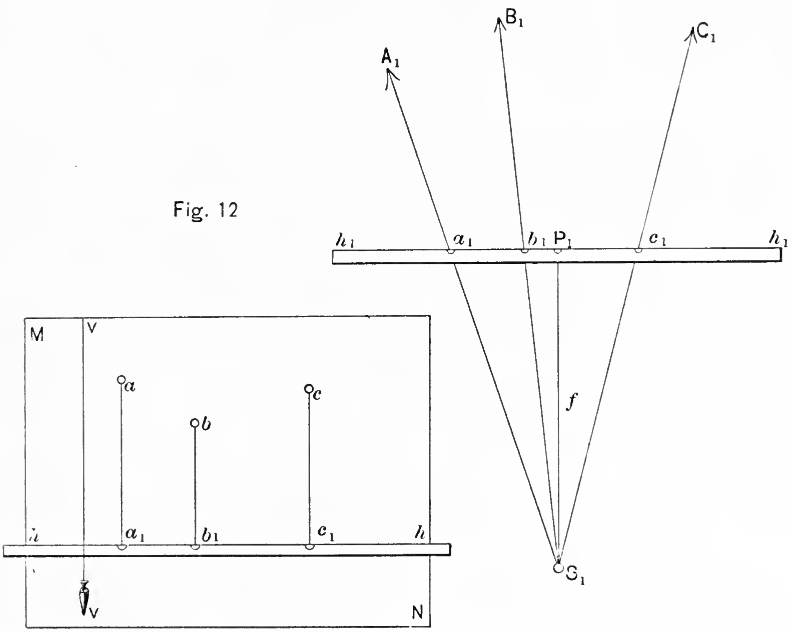

B₁
C₁
A₁
h₁
a₁
b₁
P₁
c₁
h₁
f
G₁
M
V
a
b
c
h
a₁
b₁
c₁
h
V
N

Fig. 12

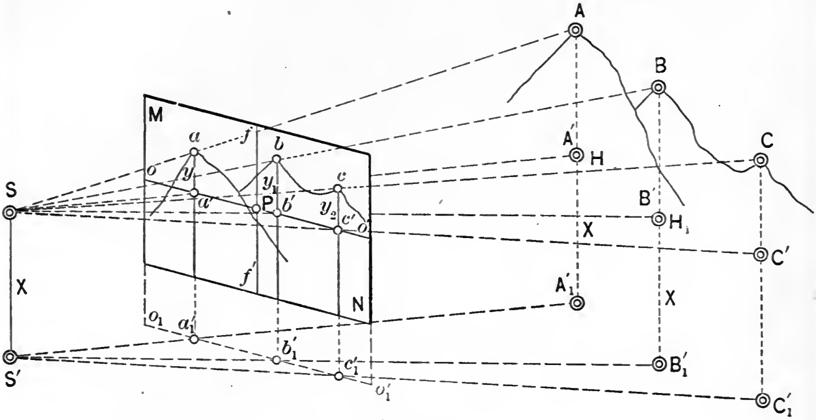

A
B
C
M
a
f
b
c
o
y
y1
y2
A'
H
S
a'
P
b'
c'
o'
B'
H1
X
C'
f'
X
A'1
N
X
o1
a'1
b'1
c'1
B'1
S'
o'1
C'1

Fig. 13

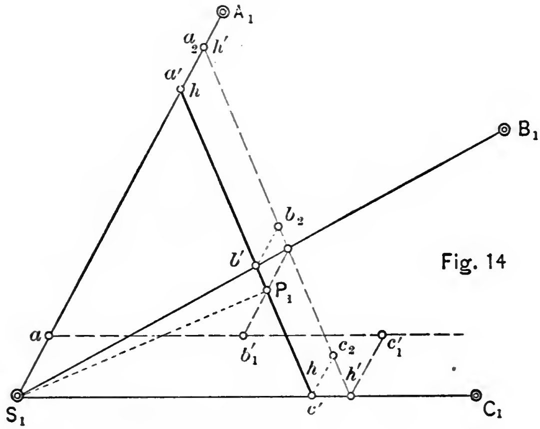
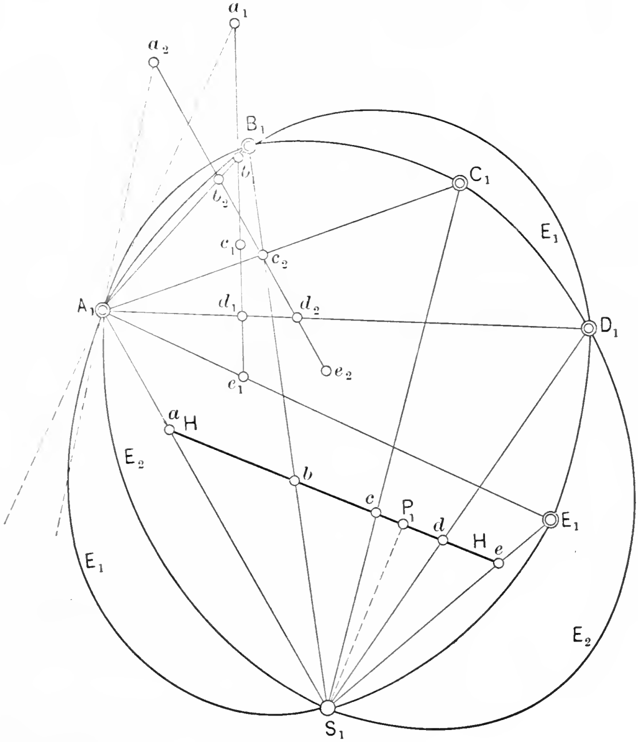

A1
a2
h'
a'
h
B1
b2
b'
P1
a
b'1
c2
c'1
h
h'
S1
c'
C1

Fig. 14



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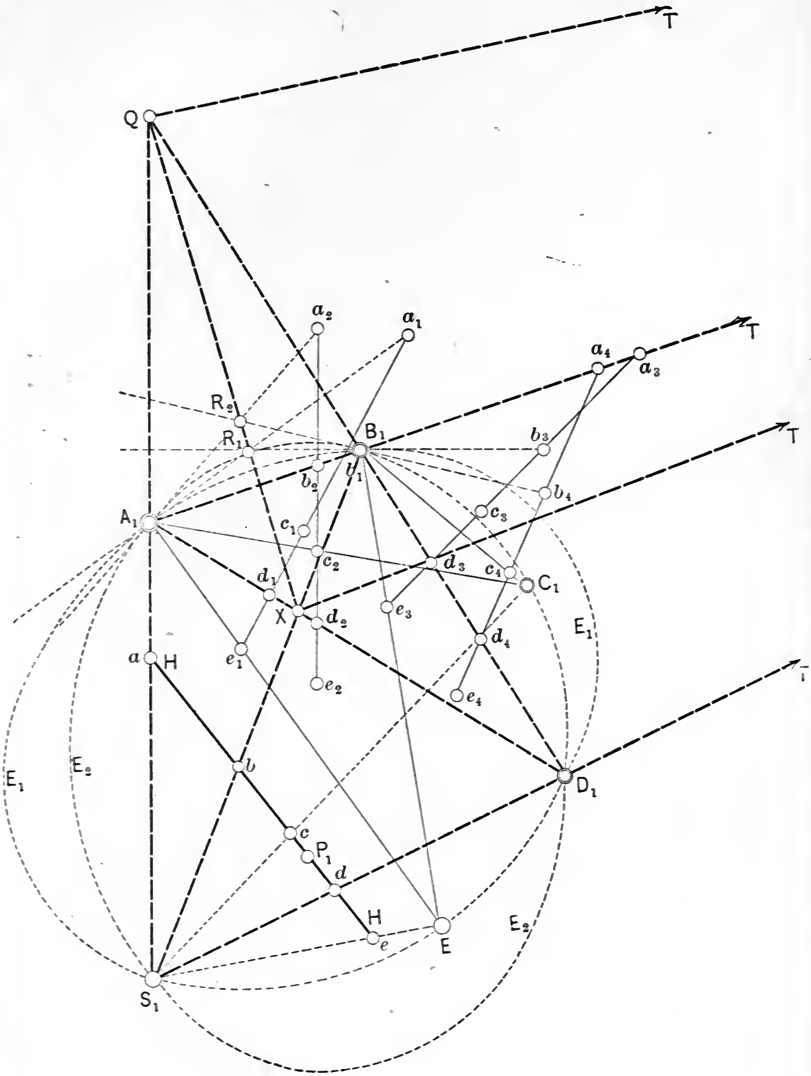
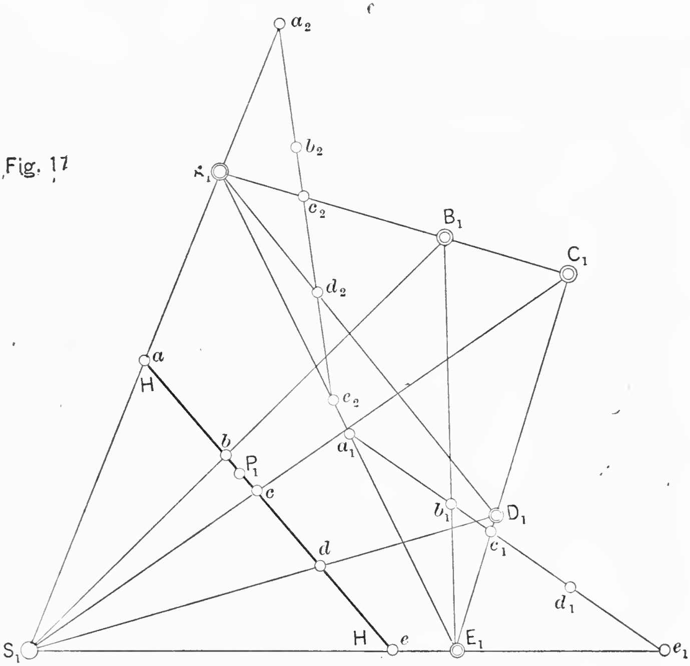

T
Q
a_2
a_1
T
a_4
a_3
R_2
R_1
B_1
b_3
T
b_2
b_1
b_4
A_1
c_1
c_3
c_2
d_3
c_4
C_1
d_1
X
d_2
e_3
E_1
d_4
a
H
e_1
e_2
T
e_4
E_1
E_2
b
D_1
c
P_1
d
H
e
E
E_2
S_1

Fig. 16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A_1
c_2
B_1
C_1
d_2
a
H
e_2
b
a_1
P_1
c
b_1
D_1
c_1
d
d_1
S_1
H
e
E_1
e_1

Fig. 17

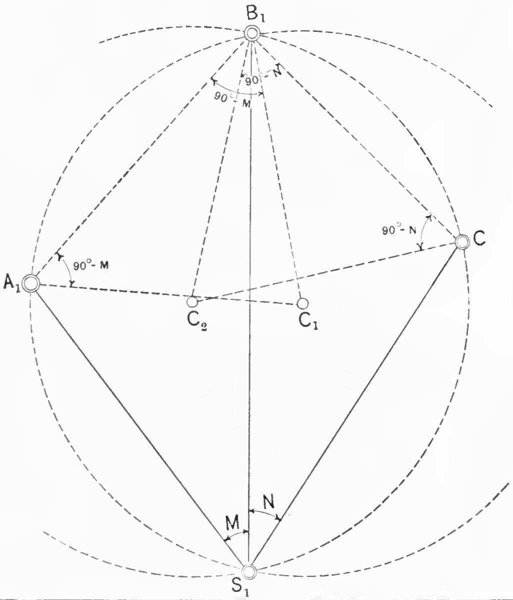

B_1
90° - N
90° - M
90° - N
C
90° - M
A_1
C_2
C_1
N
M
S_1

Fig. 18

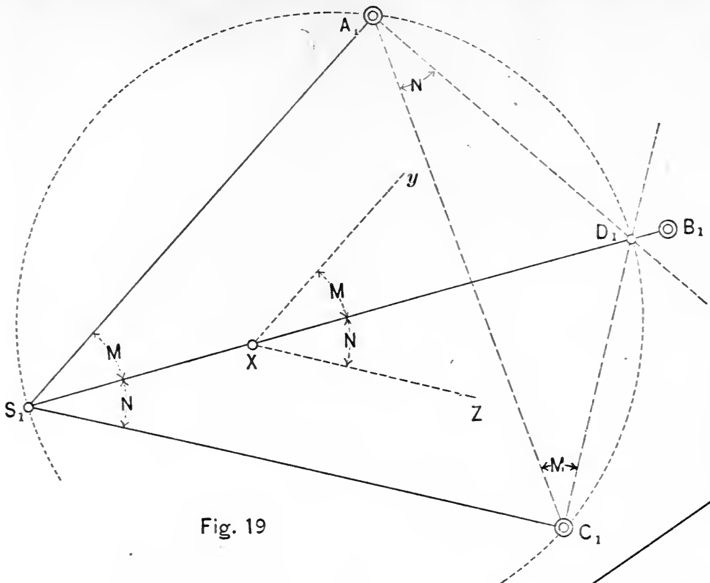


Fig. 19

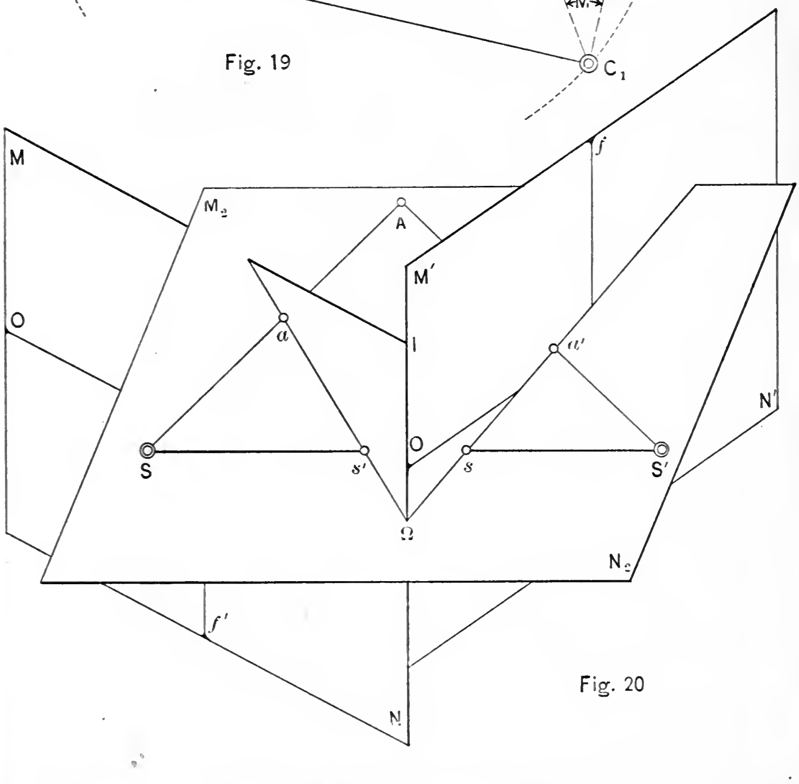


Fig. 20

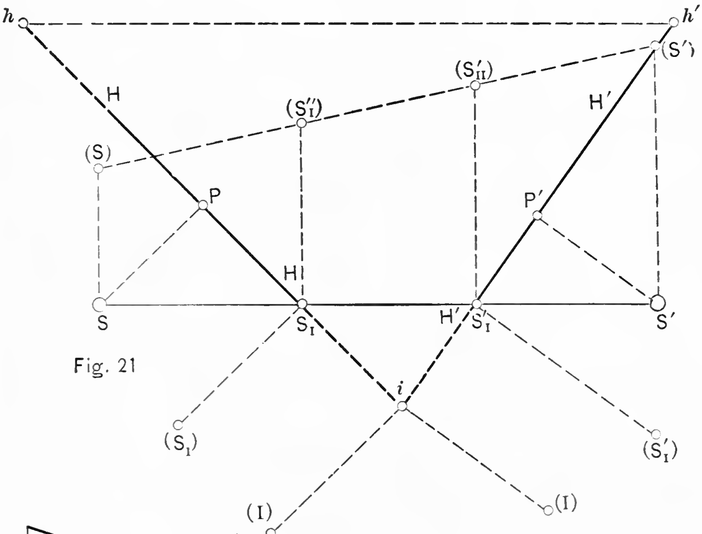
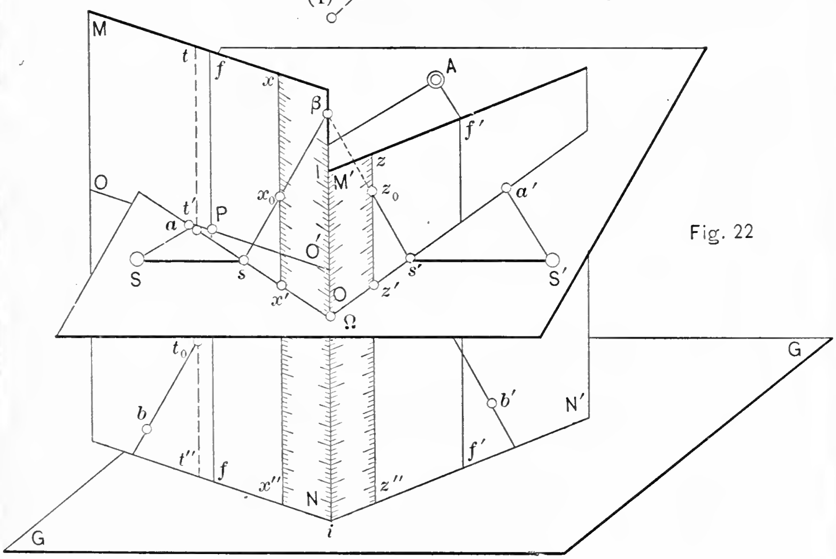

h
h′
(S′)
(S′II)
(S″I)
H
H′
(S)
P
P′
H
S
SI
H′
S′I
S′
i
(SI)
(S′I)
(I)
(I)

Fig. 21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t
f
x
A
β
f′
z
M′
O
x0
z0
a′
t′
P
a
O′
S
s
s′
S′
x′
O
z′
Ω
t0
G
b
b′
N′
f′
t″
f
x″
z″
N
i
G

Fig. 22

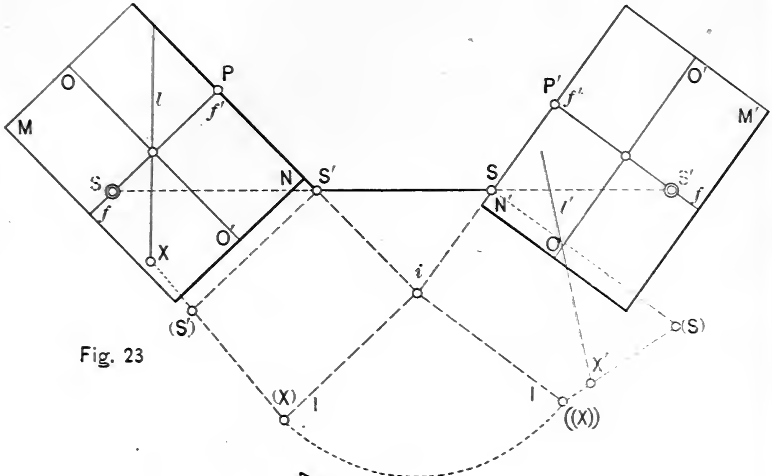

M
O
P
f′
l
S
f
N
S′
O′
X
(S′)
i
(X)
l
S
N′
P′
f′
O′
M′
S′
f
l′
O′
(S)
X′
((X))

Fig. 23

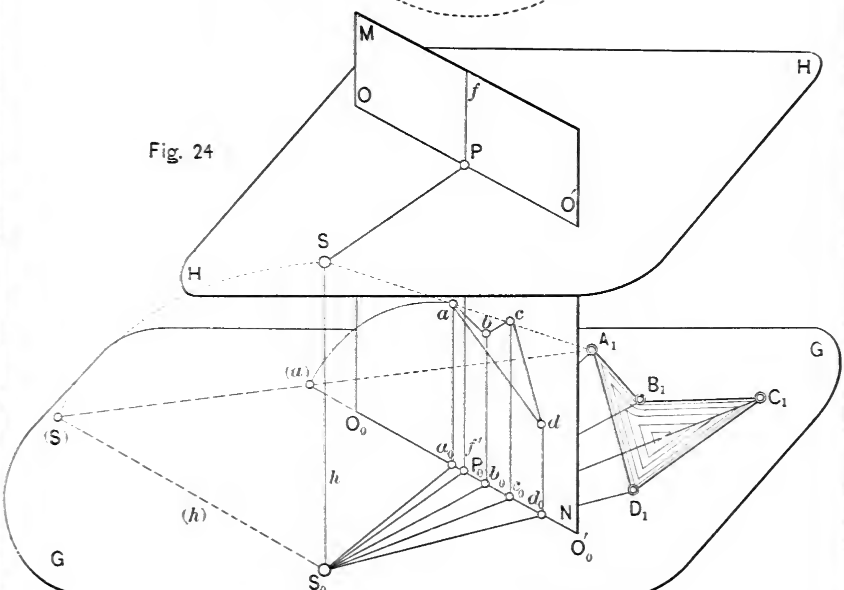

M
O
f
P
O′
H
S
H
a
b
c
A1
G
(a)
B1
C1
O0
d
(S)
a0
f′
P0
b0
c0
d0
N
D1
h
(h)
G
S0
O′0

Fig. 24

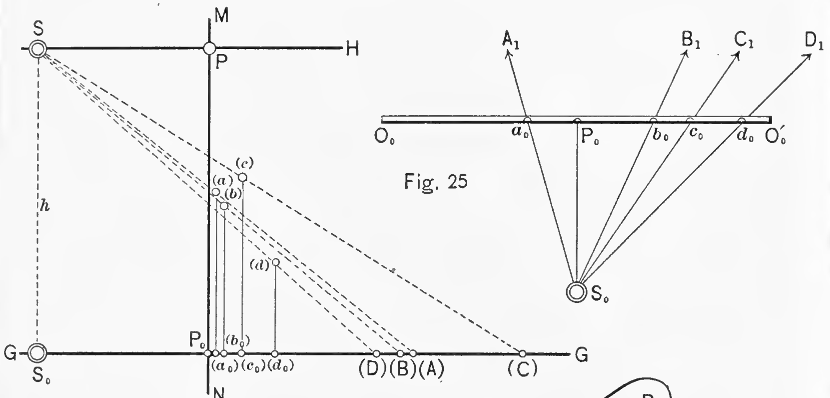

S
M
H
P
h
(c)
(a)
(b)
(d)
G
P₀
(b₀)
G
S₀
(a₀)(c₀)(d₀)
(D)(B)(A)
(C)
N
A₁
B₁
C₁
D₁
O₀
a₀
P₀
b₀
c₀
d₀
O′₀
S₀

Fig. 25

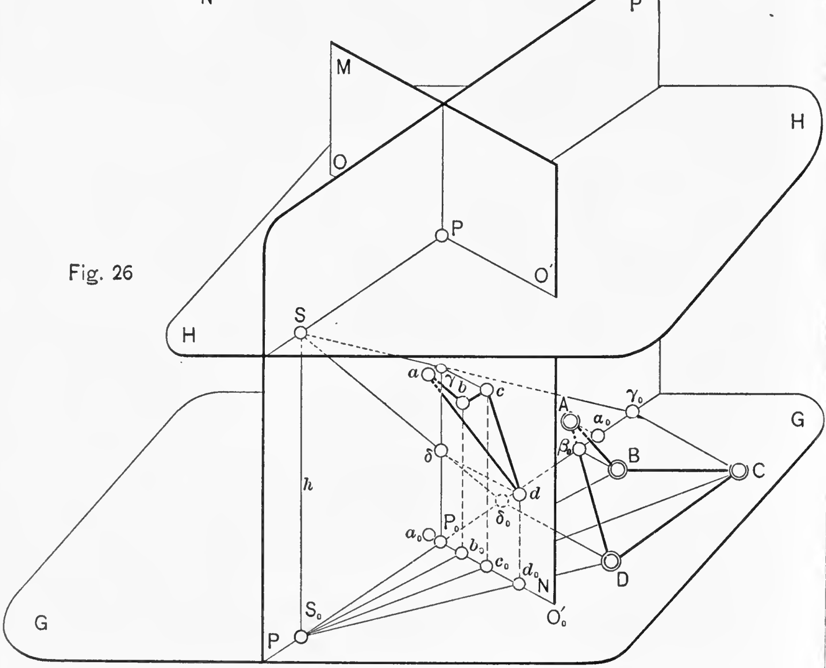

P
M
H
O
P
O′
H
S
a
γ
b
c
A
γ₀
G
α₀
β₀
B
C
δ
h
d
δ₀
a₀
P₀
b₀
c₀
d₀
N
D
O′₀
S₀
G
P

Fig. 26

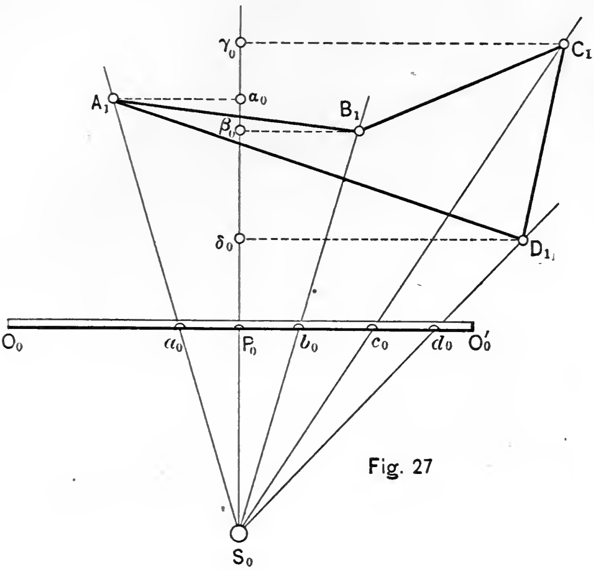

γ0
C1
A1
α0
B1
β0
δ0
D1
O0
a0
P0
b0
c0
d0
O'0
S0

Fig. 27

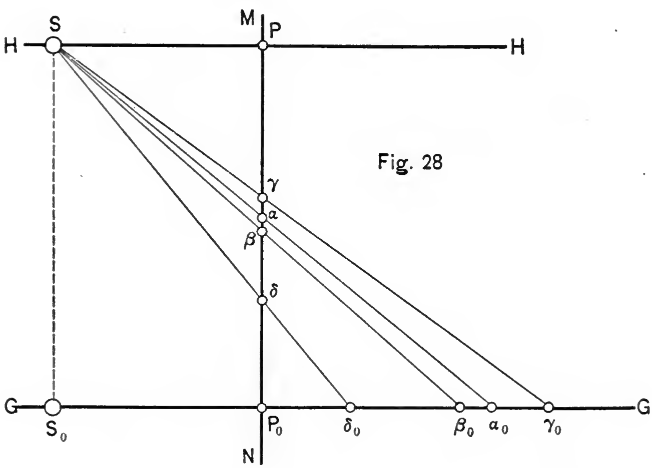

M
S
P
H
H
γ
α
β
δ
G
G
S0
P0
δ0
β0
α0
γ0
N

Fig. 28

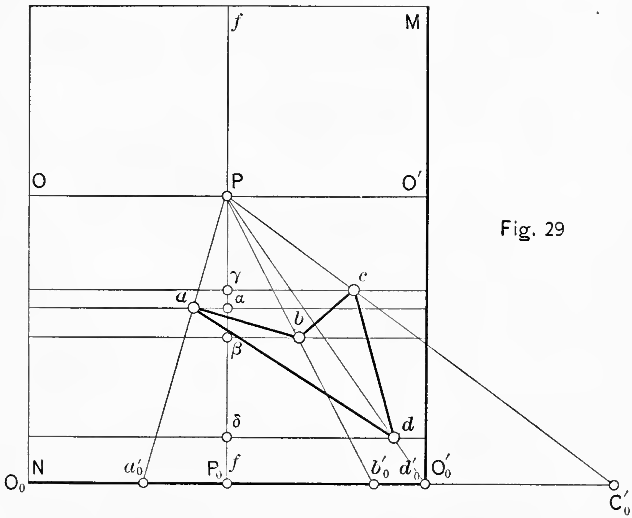

f
M
O
P
O′
γ
c
a
α
b
β
δ
d
N
a′₀
P₀
f
b′₀
d′₀
O′₀
O₀
C′₀

Fig. 29

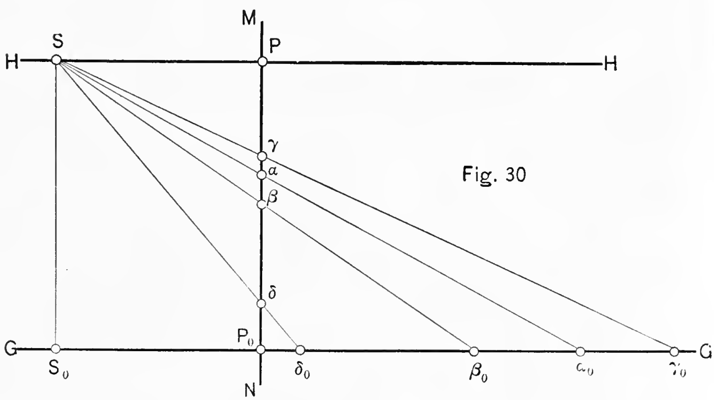
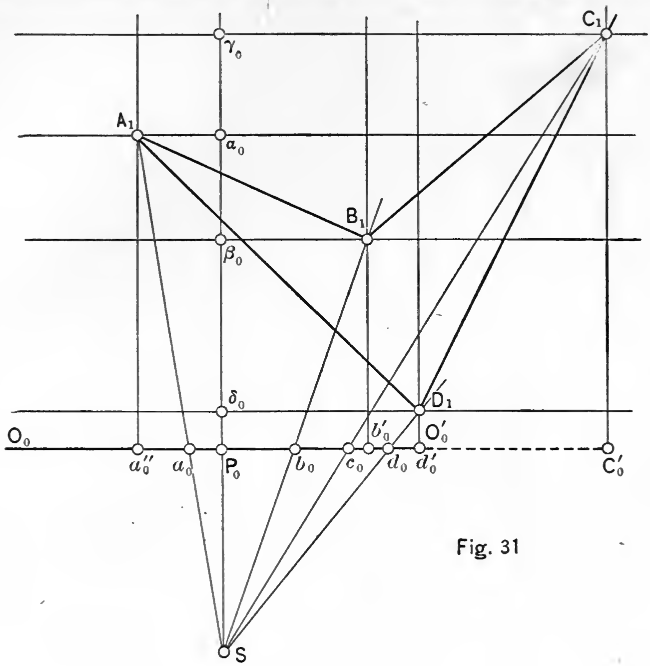
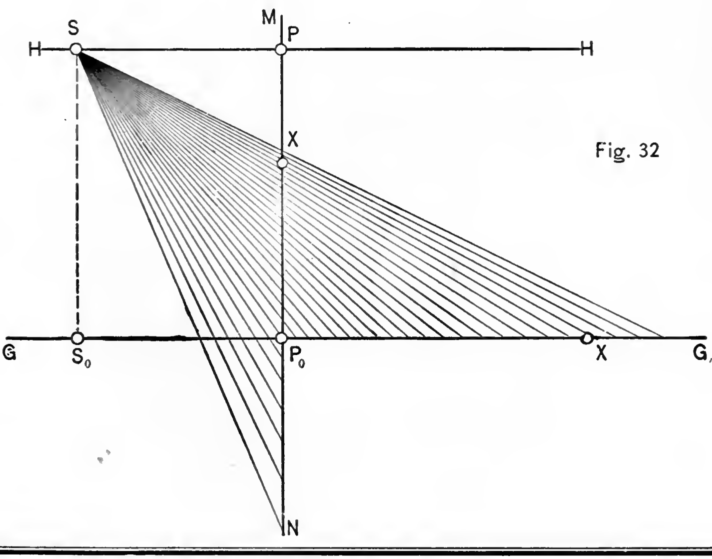

M
S
P
H
H
γ
α
β
δ
P₀
G
G
S₀
δ₀
β₀
α₀
γ₀
N

Fig. 30



C_1
γ_0
A_1
α_0
B_1
β_0
δ_0
D_1
O_0
b'_0
O'_0
a''_0
a_0
P_0
b_0
c_0
d_0
d'_0
C'_0
S

Fig. 31



M
S
P
H
H
X
G
S_0
P_0
X
G,
N

Fig. 32

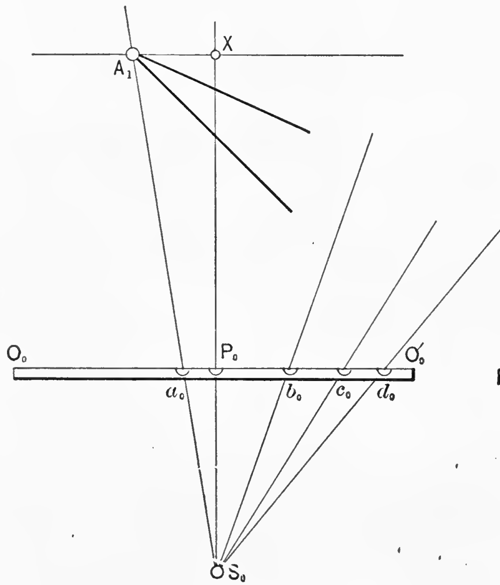


Fig. 33

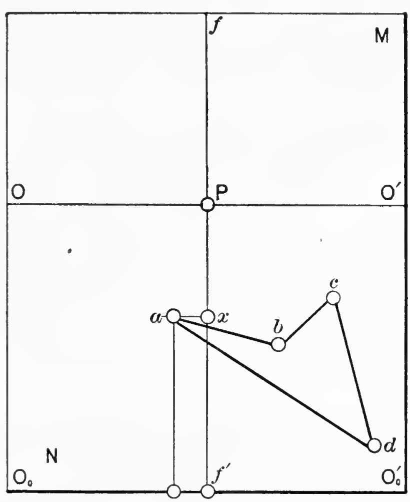


Fig. 34

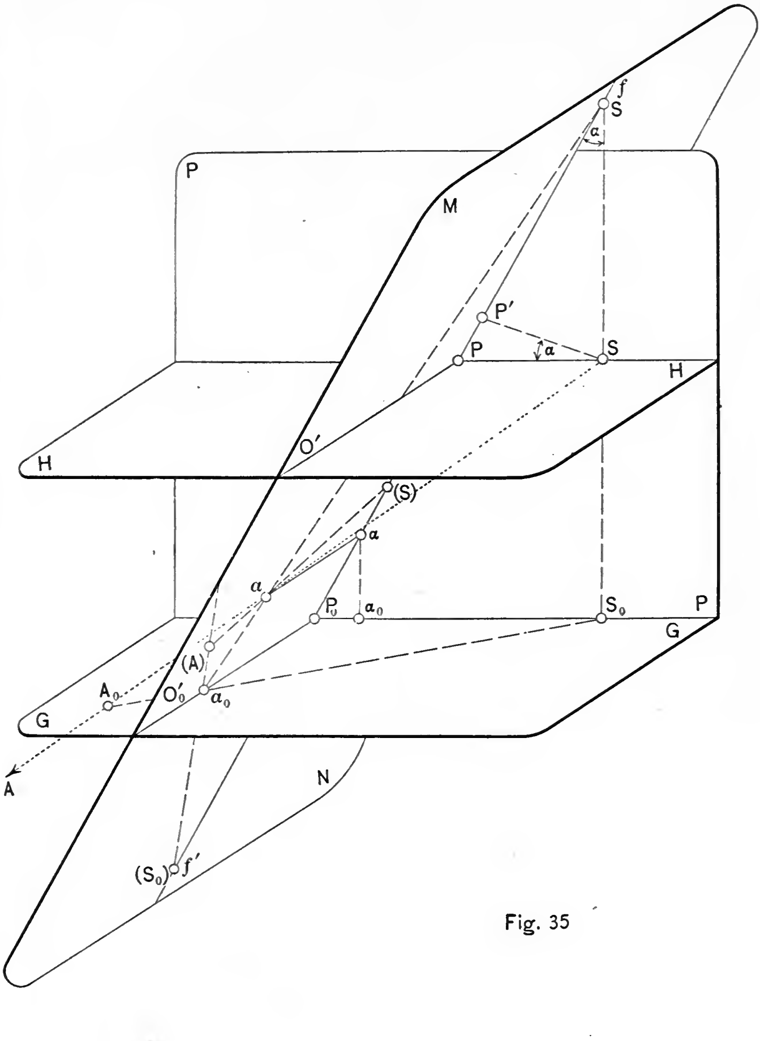


Fig. 35

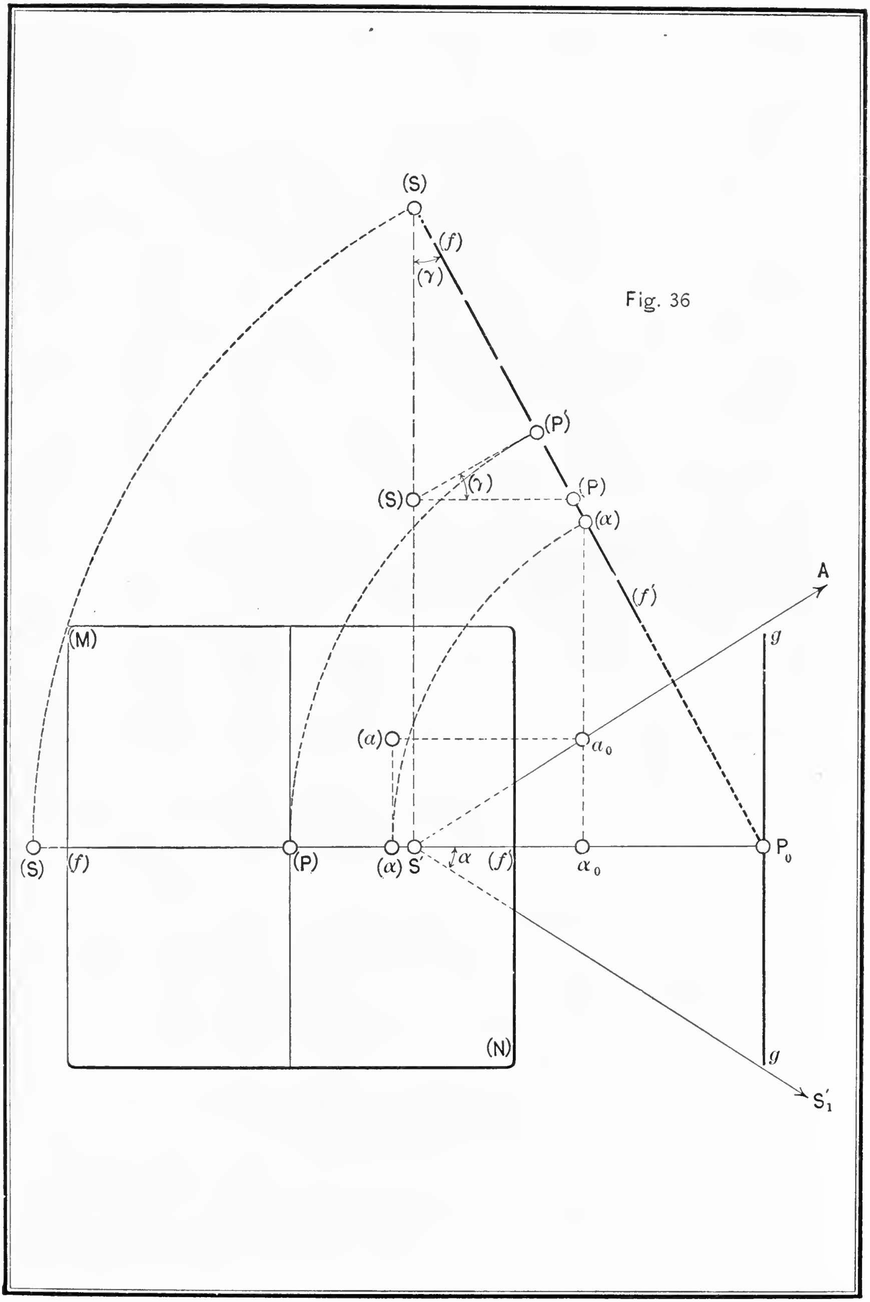
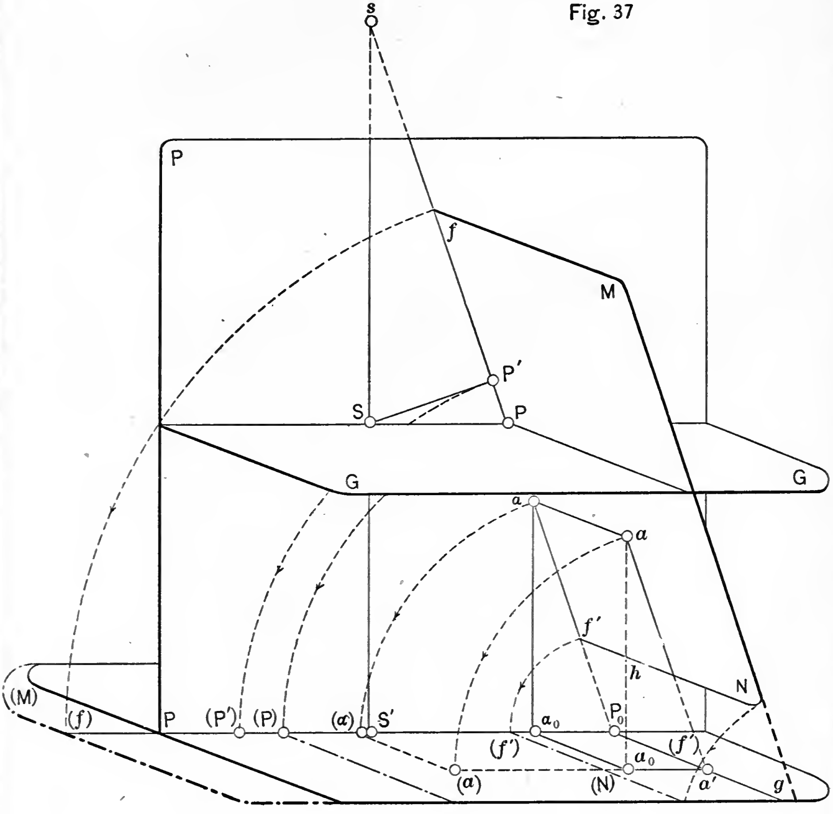

(S)
(f)
(γ)
Fig. 36
(P')
(S)
(γ)
(P)
(α)
(f')
A
g
(M)
(a)
a_0
(S)
(f)
(P)
(α)
S'
α
(f')
α_0
P_0
(N)
g
S'_1

Fig. 37



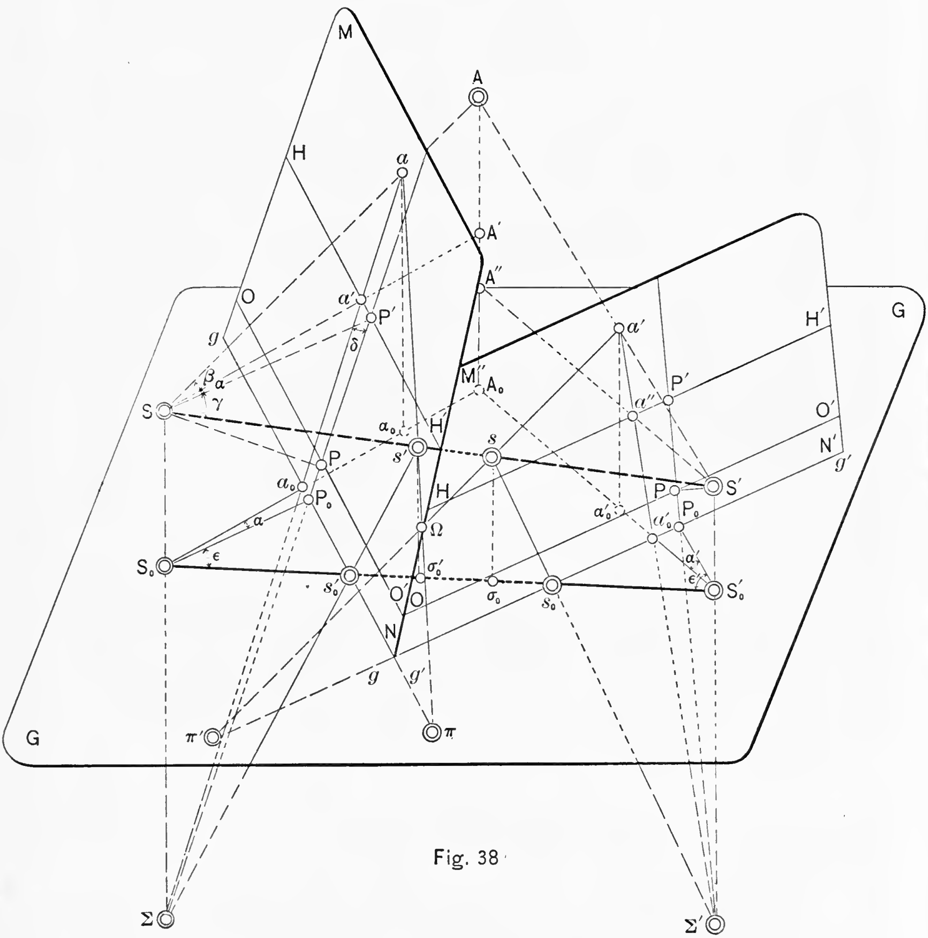
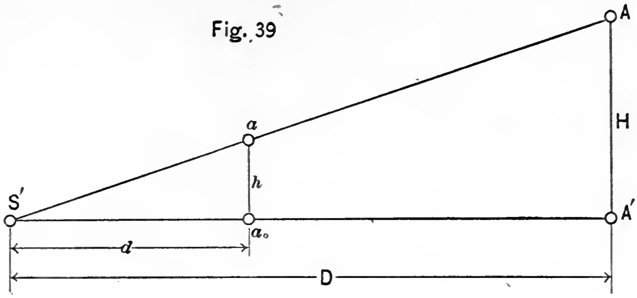

M
A
H
a
A′
A″
O
a′
P′
g
δ
β
α
γ
G
H′
M″
A₀
P′
a″
O′
S
α₀
H
s
s′
P
N′
g′
a₀
P₀
H
S′
P
α′₀
a′₀
P₀
Ω
α′
S₀
ε
σ′₀
s′₀
O′
O
σ₀
s₀
S′₀
N
g
g′
π′
π
G
Σ
Σ′

Fig. 38

Fig. 39



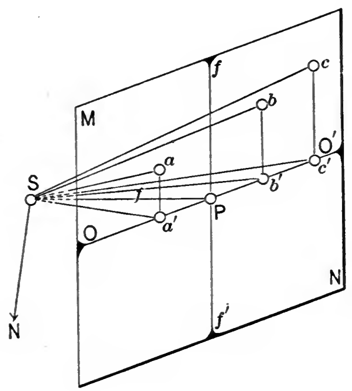
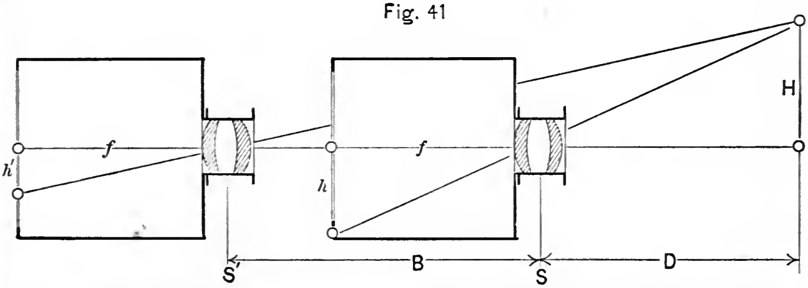


Fig. 40

Fig. 41



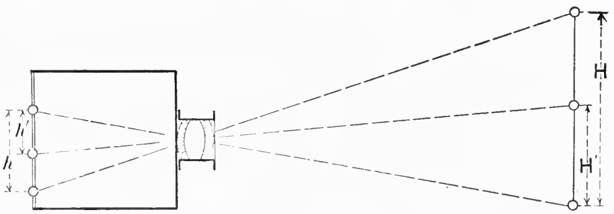

h'
h
H
H'

Fig. 42

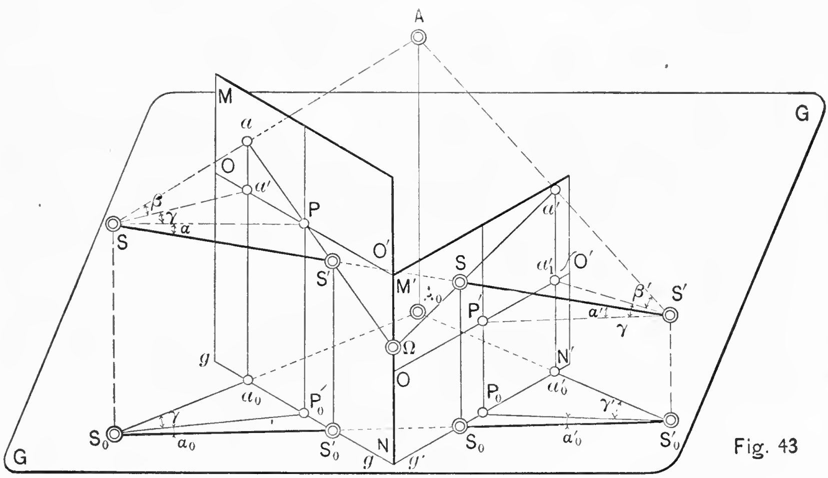

A
M
G
a
O
a'
β
γ
α
P
S
S'
O'
M'
S
a'
a'₁
O'
β'
S'
P'
a'
γ
Ω
g
O
N'
a₀
P₀
a'₀
γ'
S₀
a₀
S'₀
N
g
g'
S₀
a'₀
S'₀
G

Fig. 43

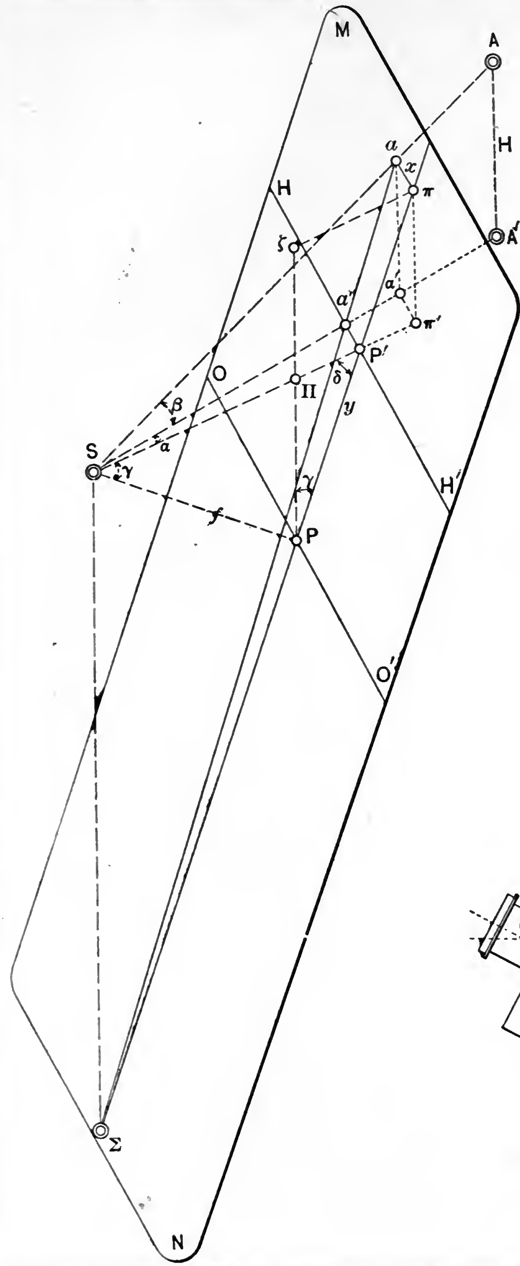


Fig. 44

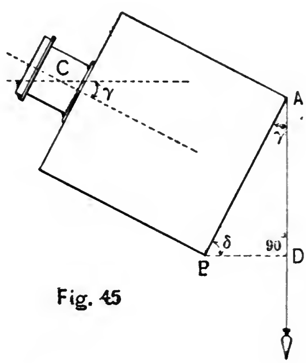
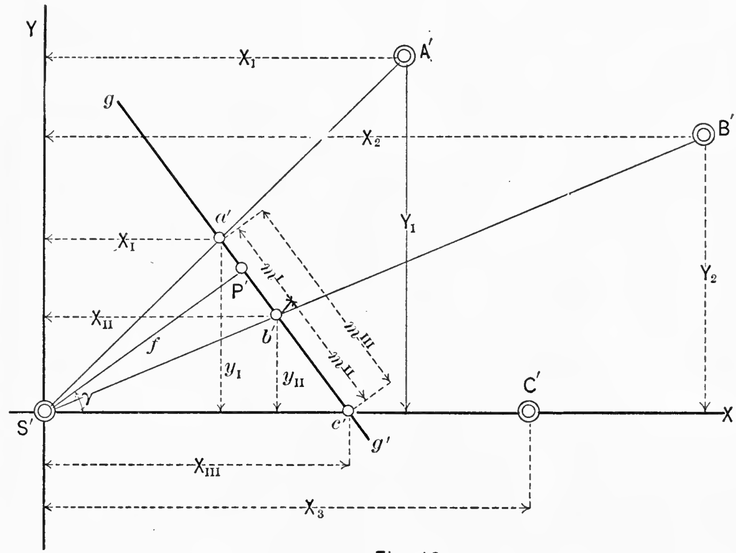
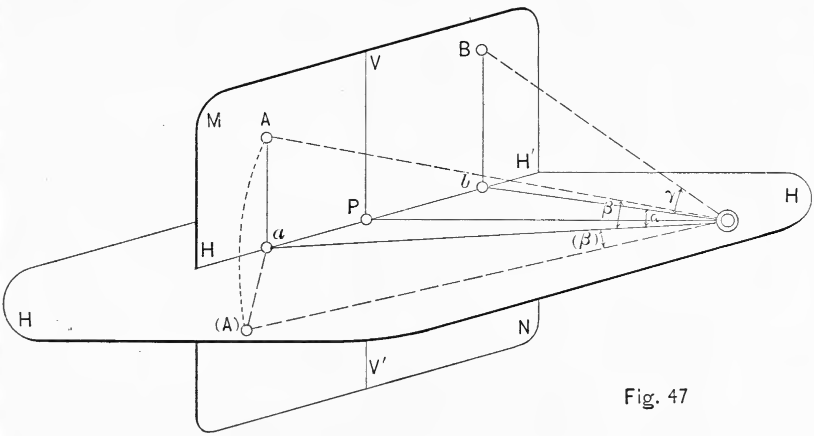


Fig. 45



Y
X
A′
B′
C′
S′
g
g′
a′
b′
c′
P′
f
γ
X_1
X_2
X_3
X_I
X_{II}
X_{III}
Y_1
Y_2
y_I
y_{II}
m_I
m_{II}
m_{III}

Fig. 46



B
V
M
A
H′
H
b
P
a
β
α
γ
(β)
(A)
N
V′

Fig. 47

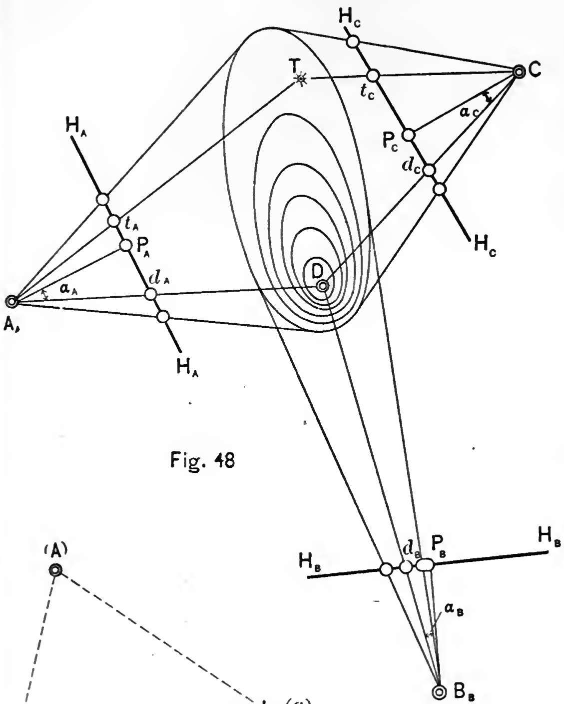


Fig. 48

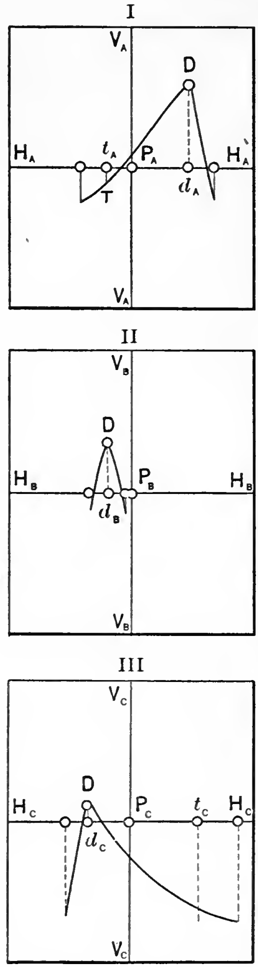


Fig. 49

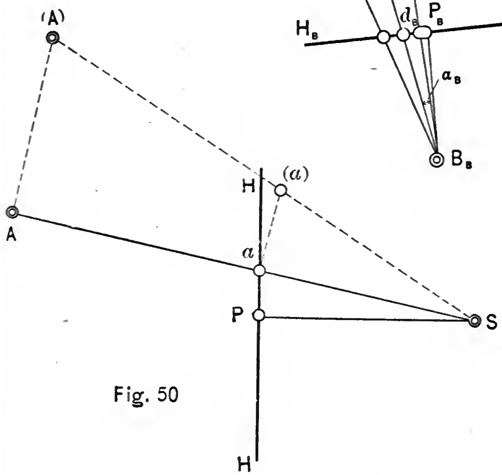


Fig. 50

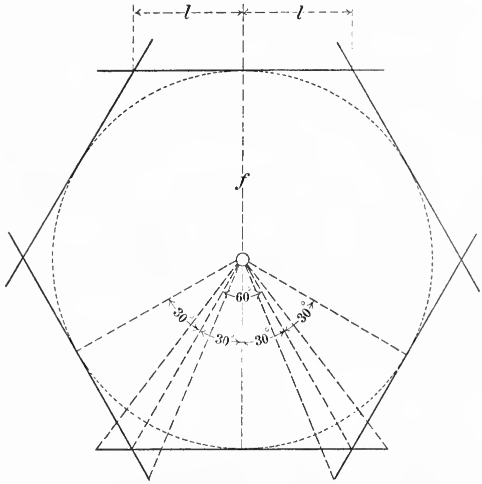


Fig. 51

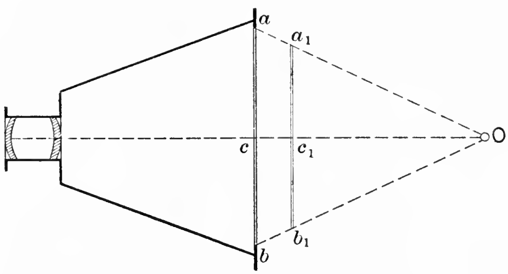


Fig. 52

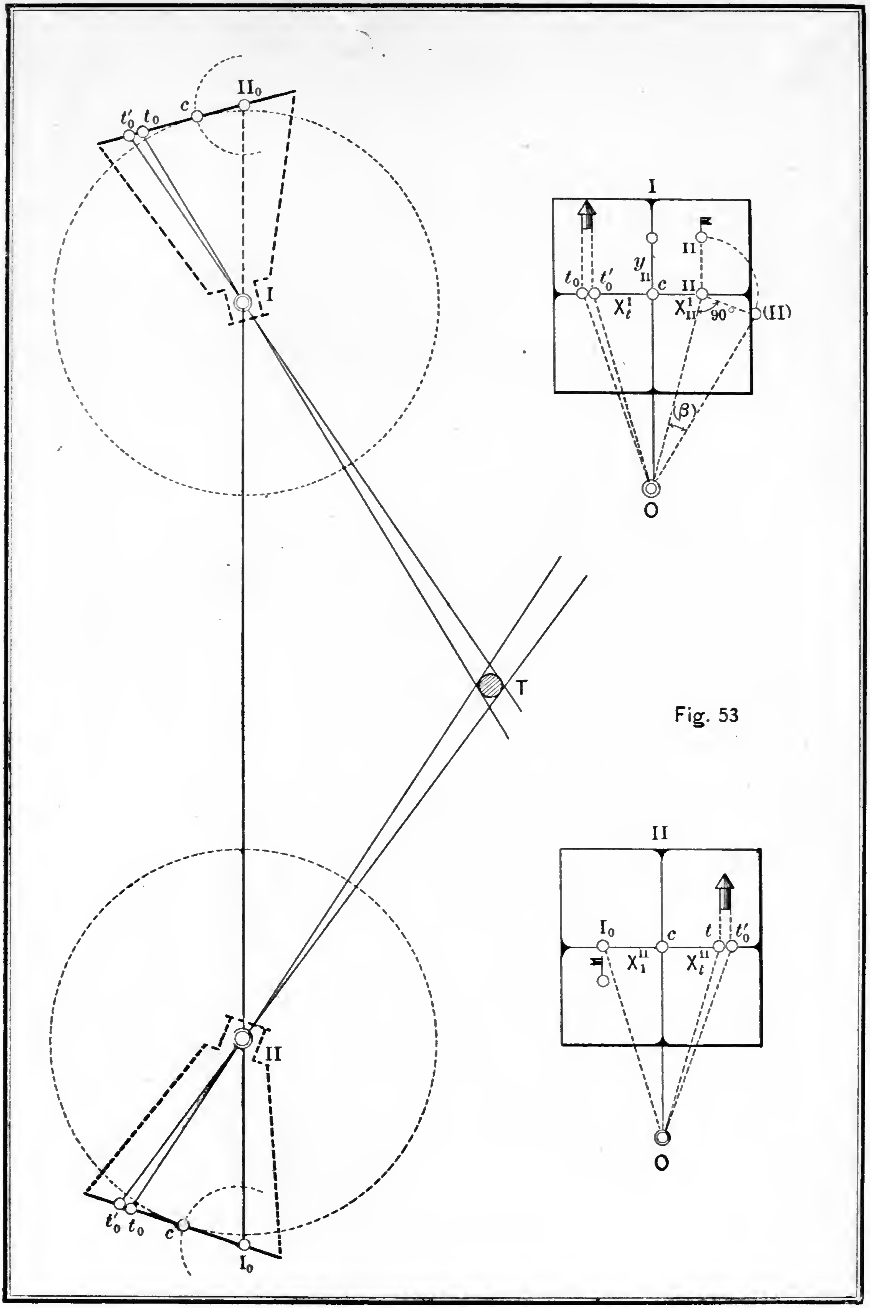


Fig. 53

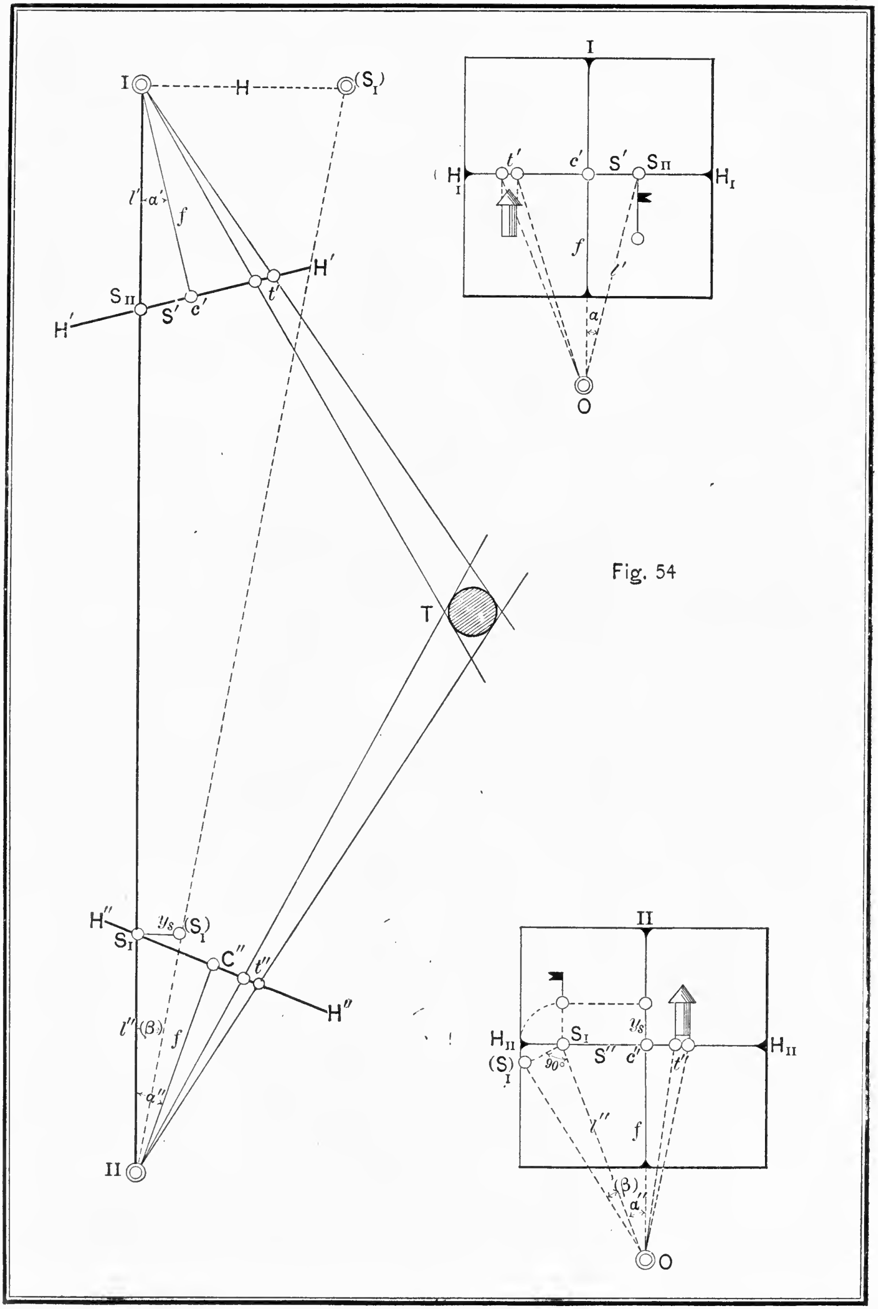


Fig. 54

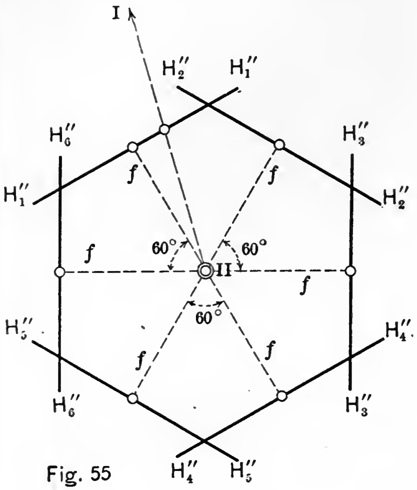


Fig. 55

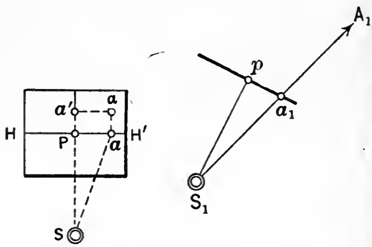
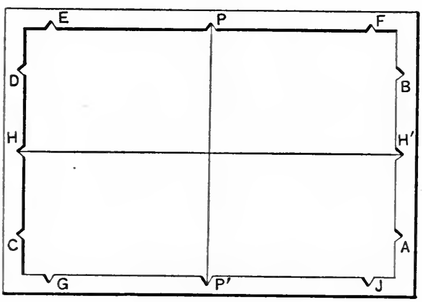


Fig. 56



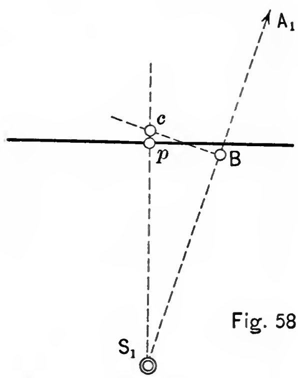


Fig. 58

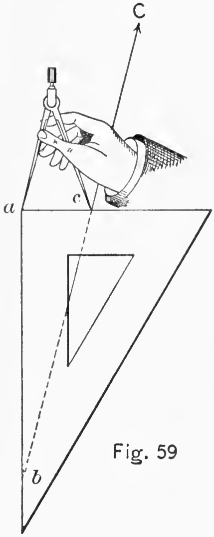


Fig. 59

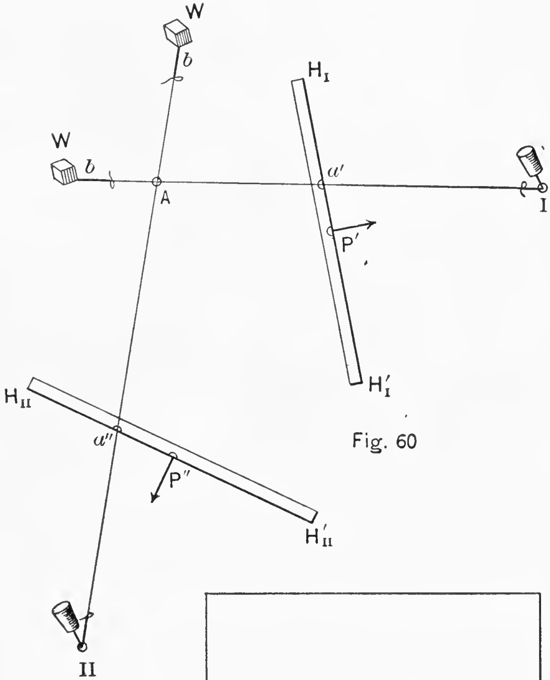


Fig. 60

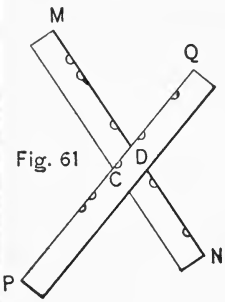


Fig. 61

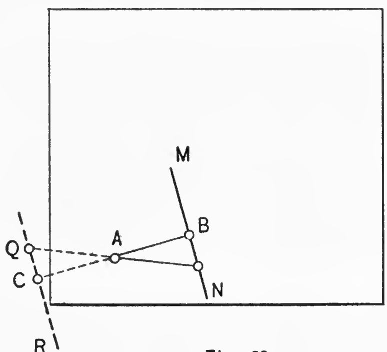


Fig. 62

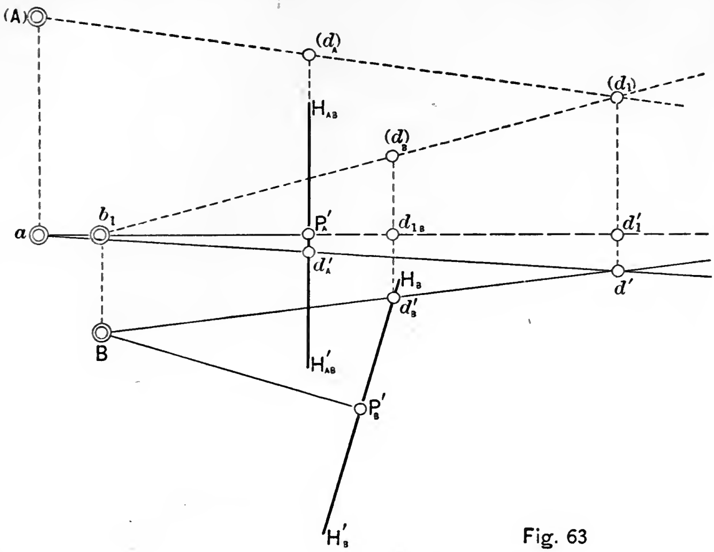
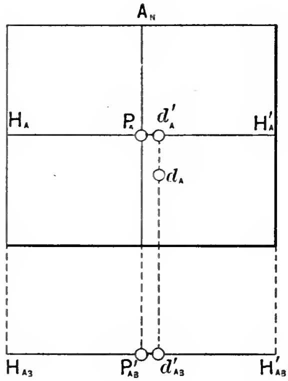
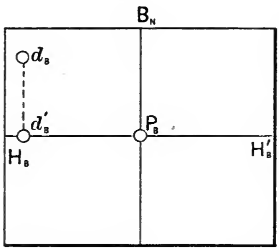

(A)
(d)
(d1)
HAB
(d)
b1
a
P'A
d1B
d'1
d'A
HB
d'
d'B
B
H'AB
P'B
H'B

Fig. 63


AN
HA
PA
d'A
H'A
dA
HAB
P'AB
d'AB
H'AB


BN
dB
d'B
PB
HB
H'B

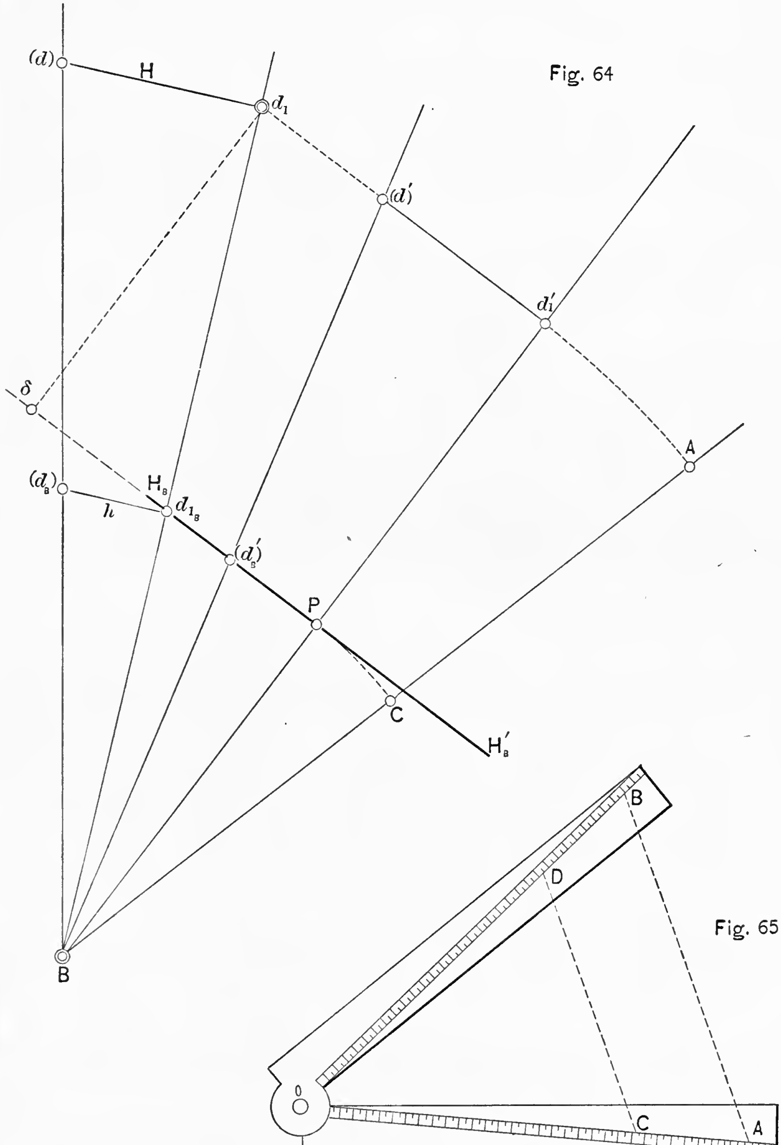


Fig. 64

Fig. 65

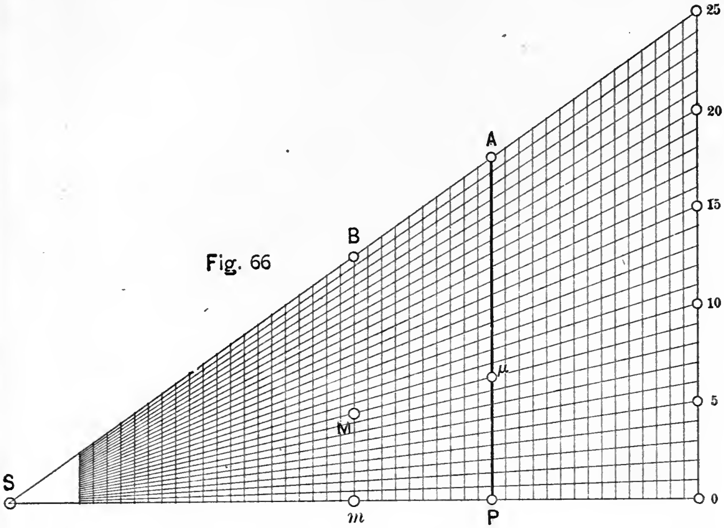


Fig. 66

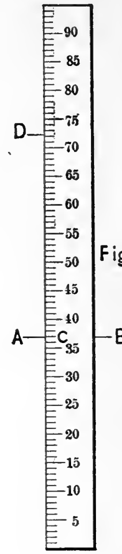


Fig. 67

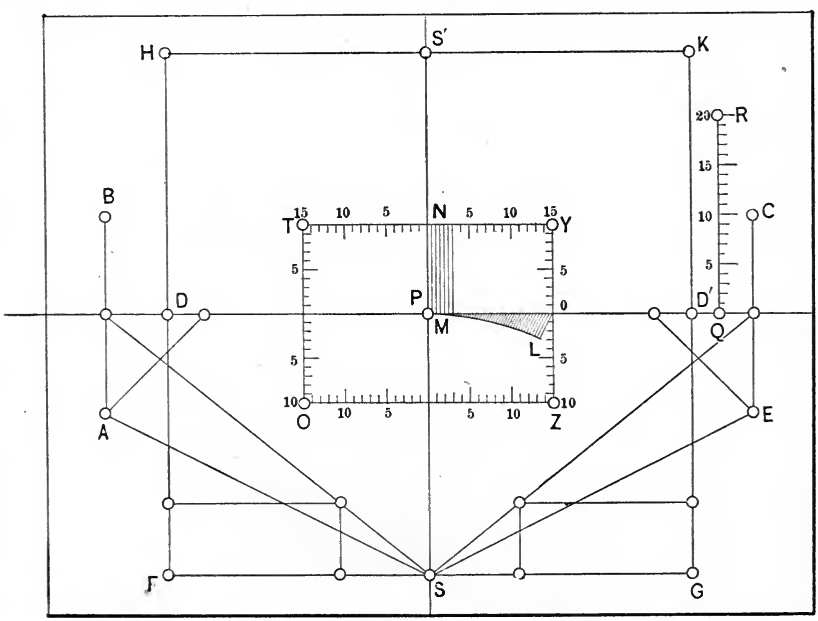
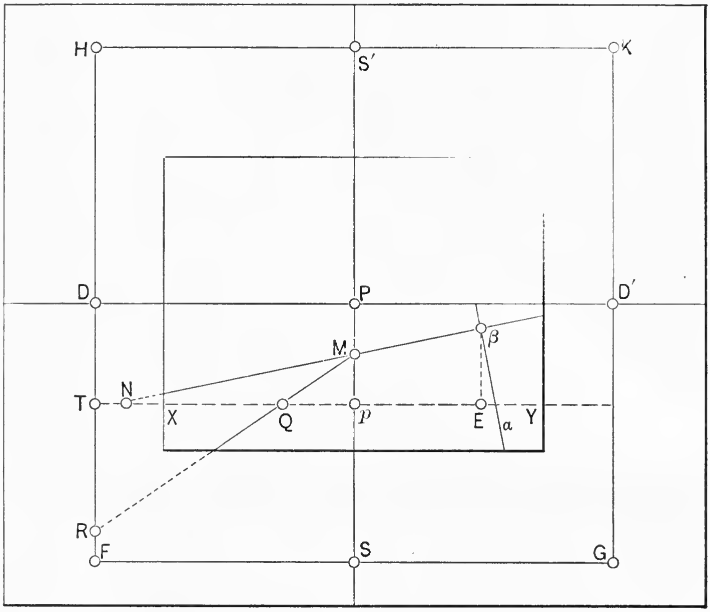


Fig. 68



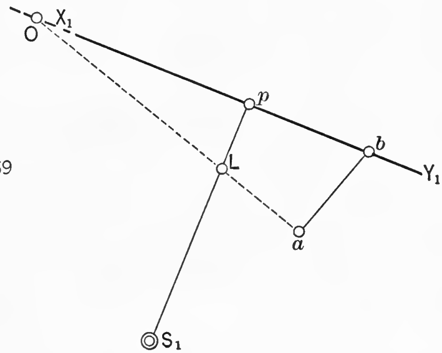
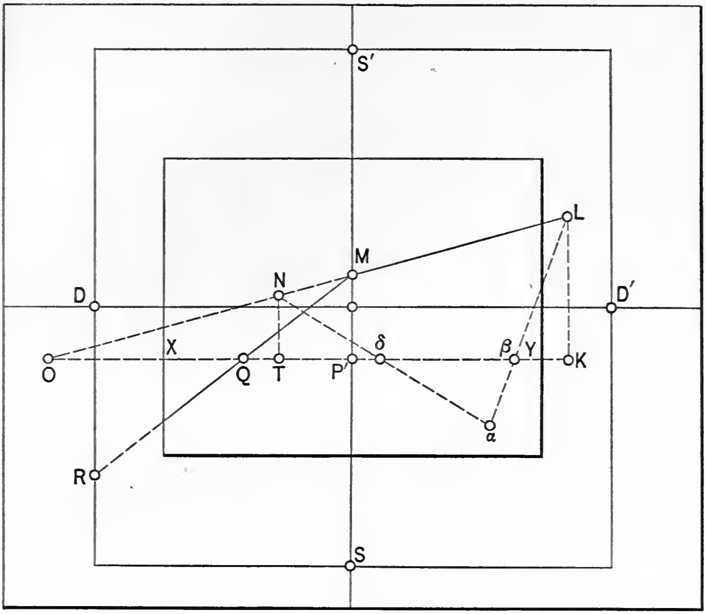


Fig. 69



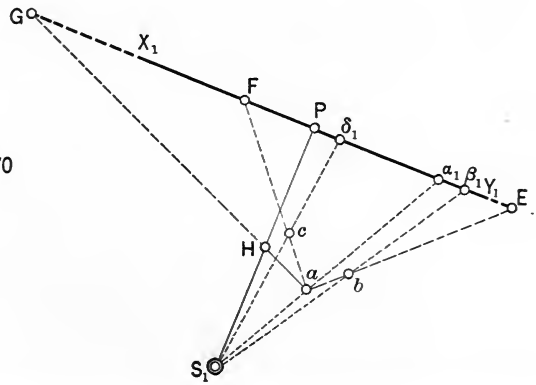
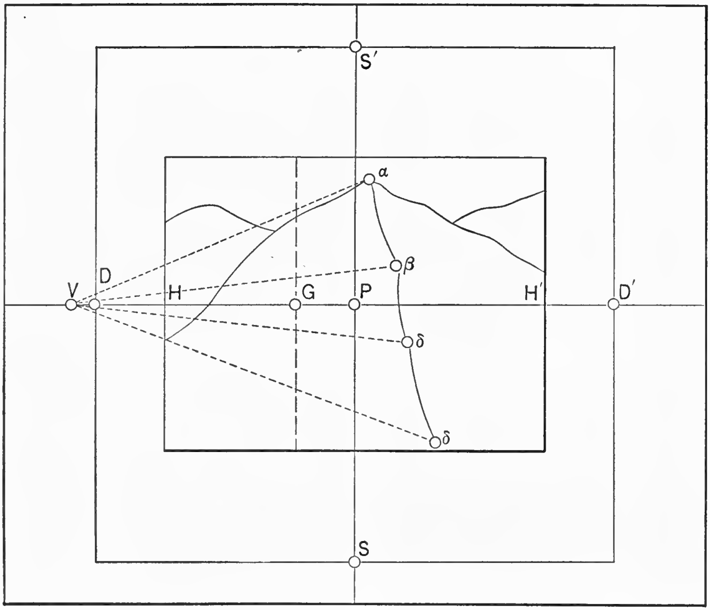


Fig. 70



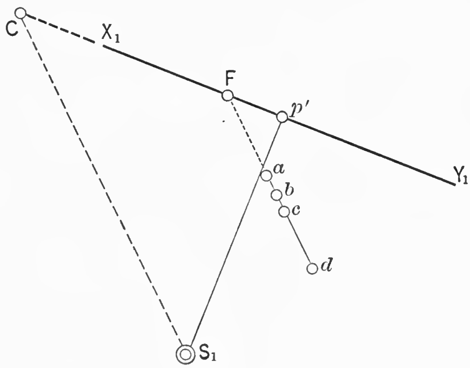
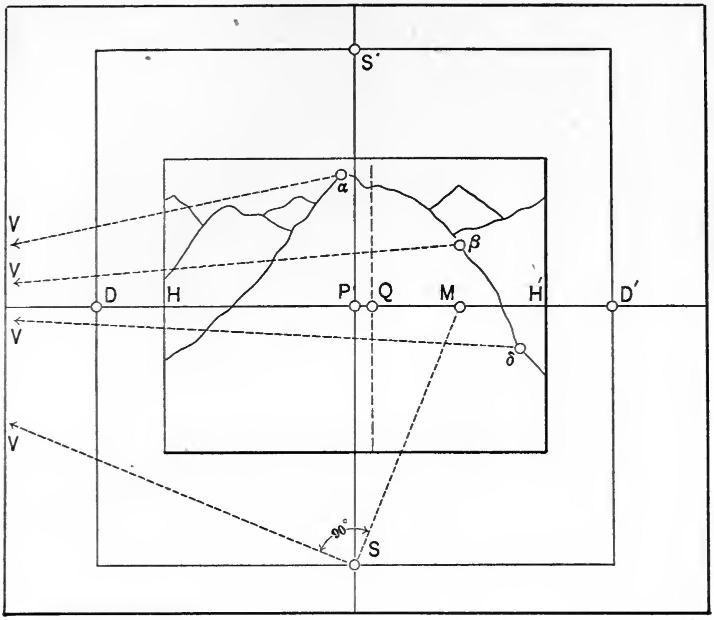


Fig. 71



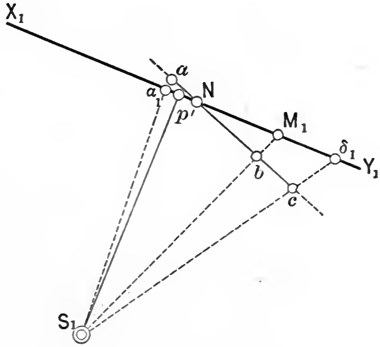
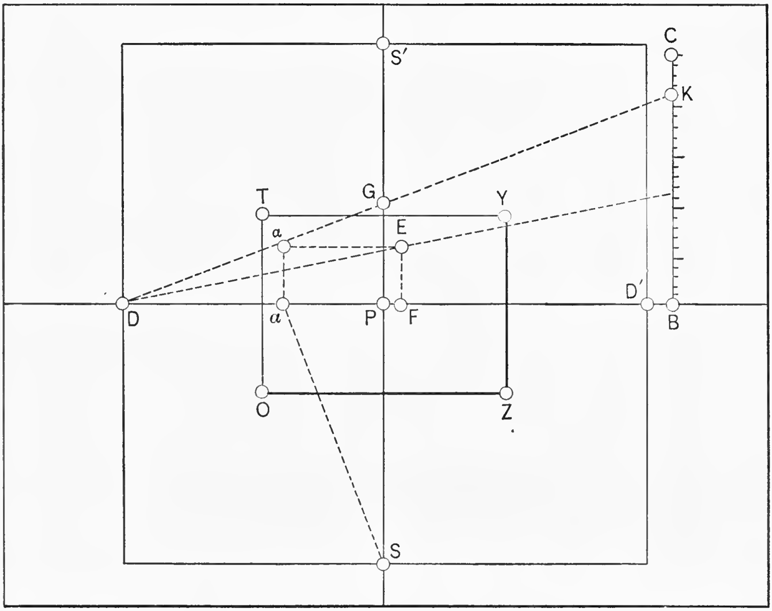


Fig. 72

Fig. 73



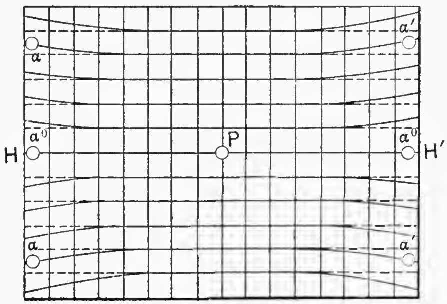


Fig. 74

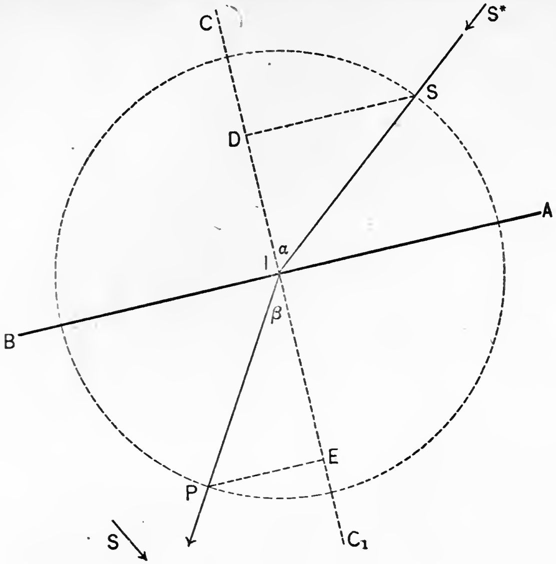


Fig. 75

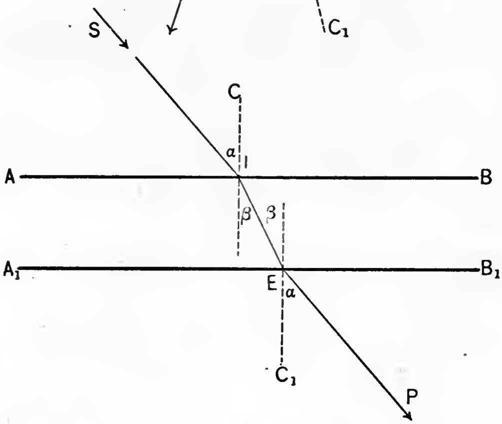


Fig. 76

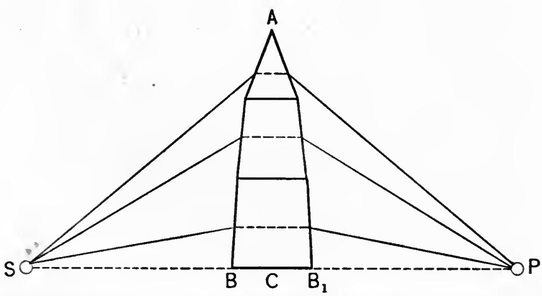
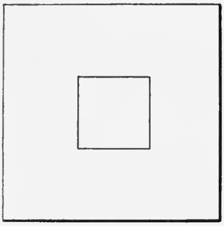


Fig. 77

Fig. 78



TEST SCREEN

Fig. 79

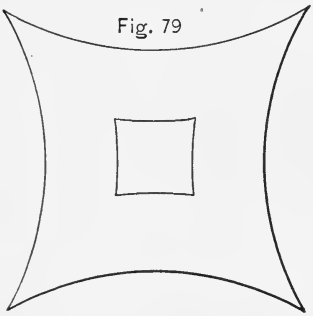


Fig. 80

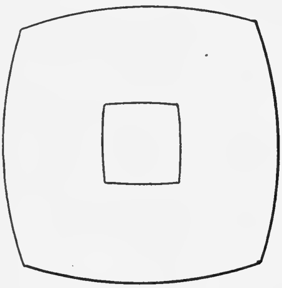
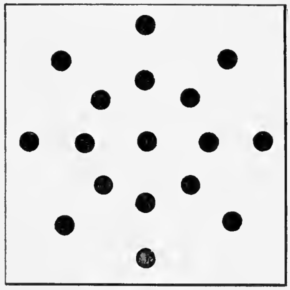
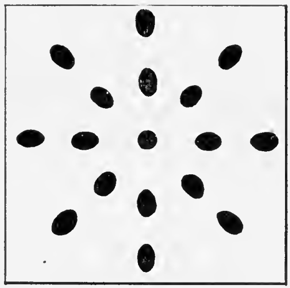


Fig. 81



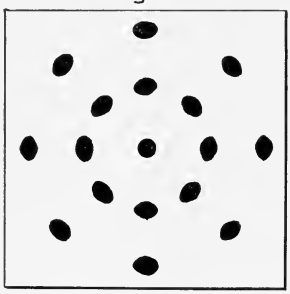
TEST SCREEN

Fig. 82



RADIAL DISTORTION

Fig. 83



TANGENTIAL DISTORTION

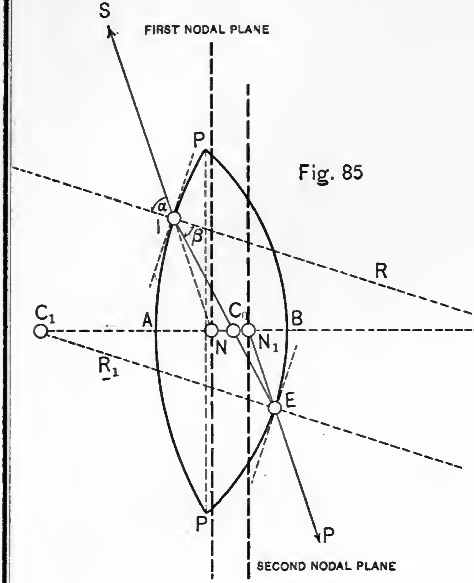
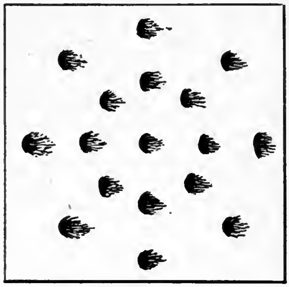


Fig. 85

Fig. 84



FLARE SPOTS

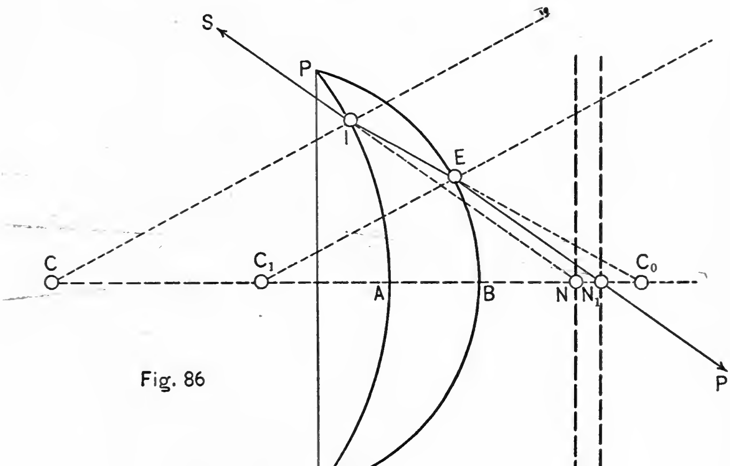


Fig. 86

Fig. 87

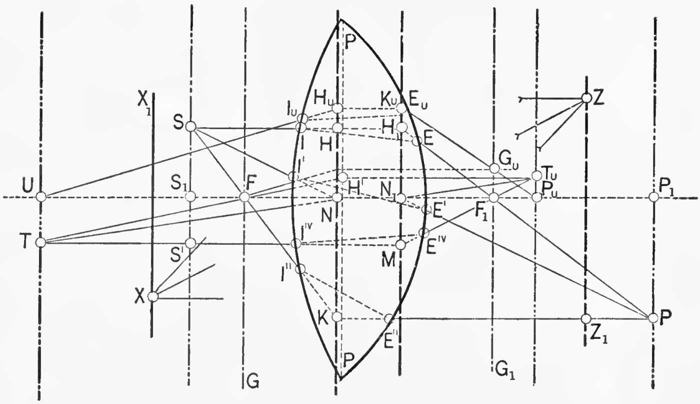
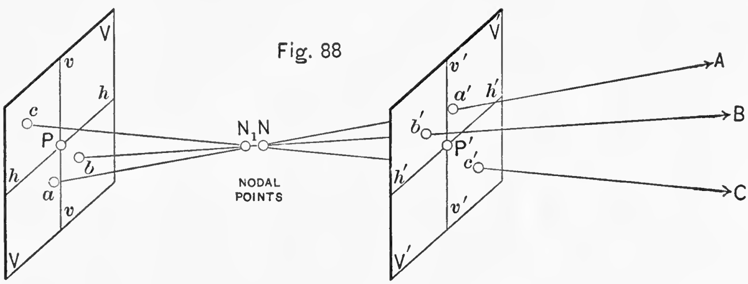

P
X
S
I_U
H_U
K_U
E_U
Z
H
H
E
I'
G_U
T_U
U
S_1
F
H'
N_1
P_U
P_1
N
E'
F_1
T
I^{IV}
E^{IV}
S'
M
I^{II}
X
K
P
E^{II}
Z_1
P
G
G_1

Fig. 88


V
v
h
c
P
b
h
a
v
V
N_1 N
NODAL POINTS
V'
v'
a'
h'
b'
P'
c'
h'
v'
V'
A
B
C

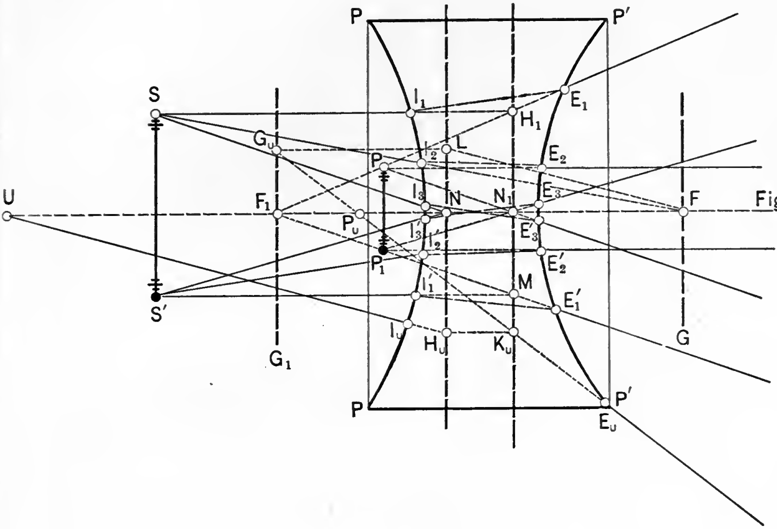

P
P′
S
S′
U
G_u
G_1
G
F_1
F
P_u
P_1
I_1
I_2
I_3
I_3'
I_2'
I_1'
I_u
H_1
H_u
K_u
L
N
N_1
M
E_1
E_2
E_3
E_3'
E_2'
E_1'
E_u

Fig. 89

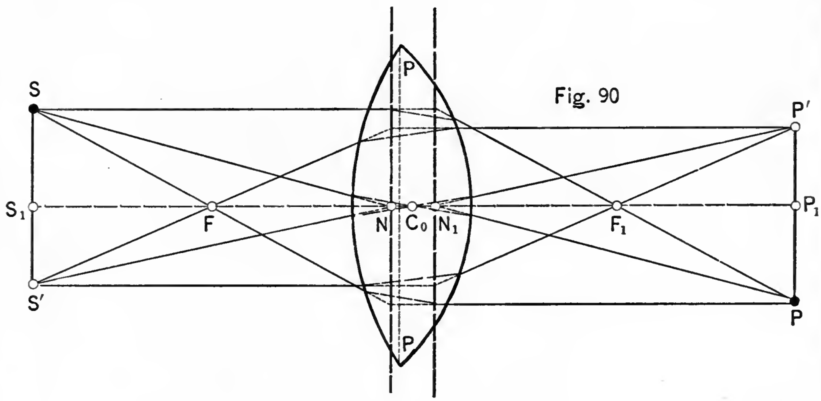

S
S_1
S′
F
P
N
C_0
N_1
F_1
P′
P_1

Fig. 90

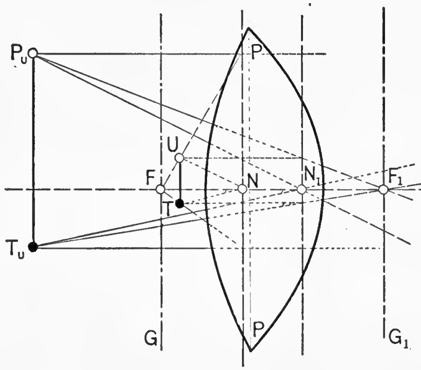


Fig. 91

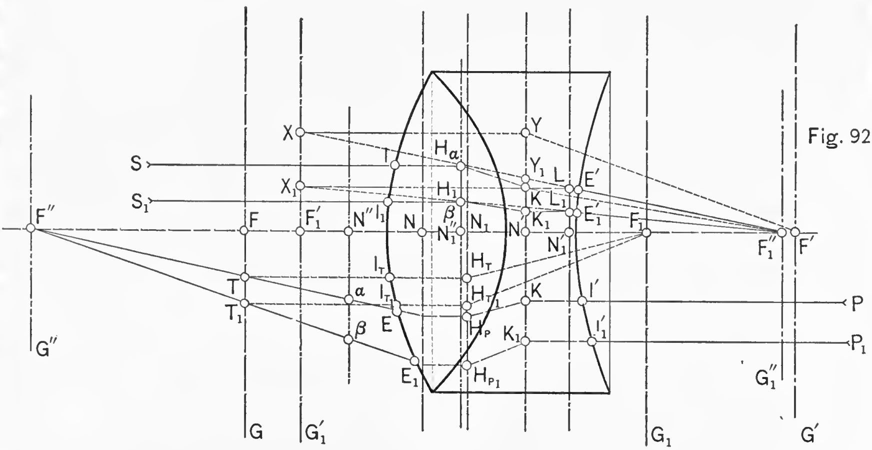


Fig. 92

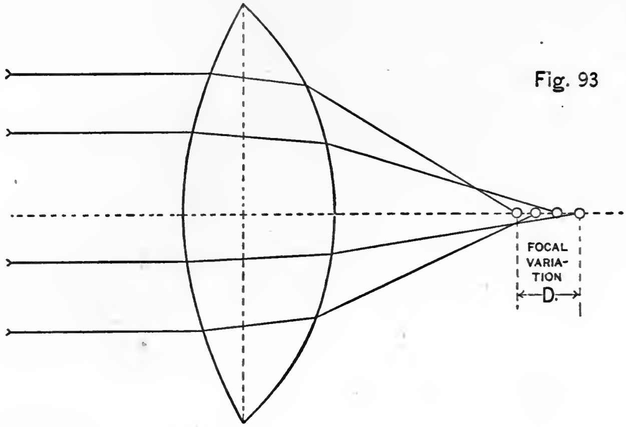


Fig. 93

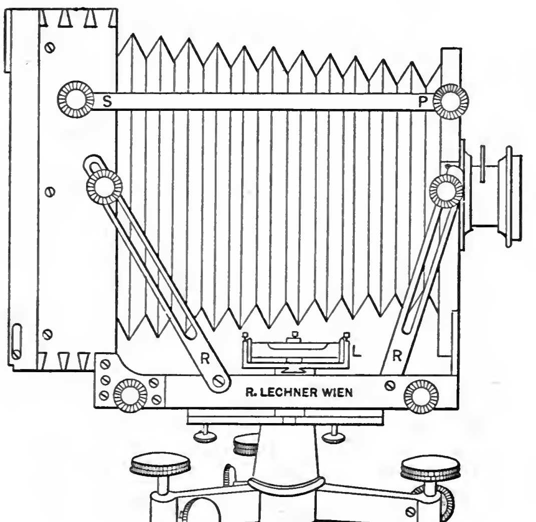


Fig. 94

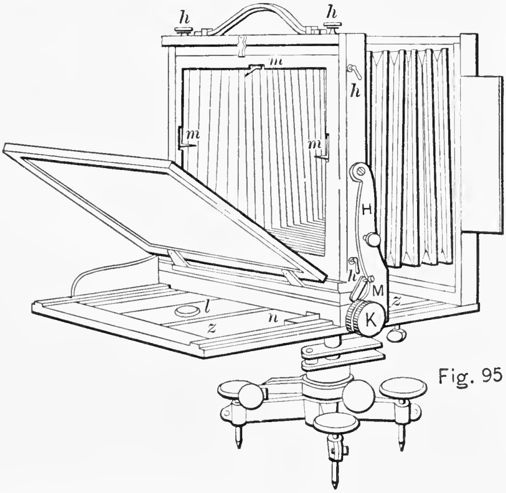


Fig. 95

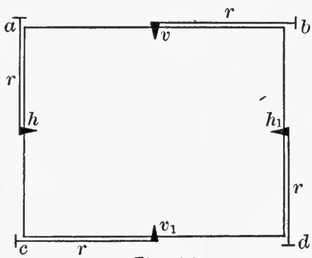


Fig. 96

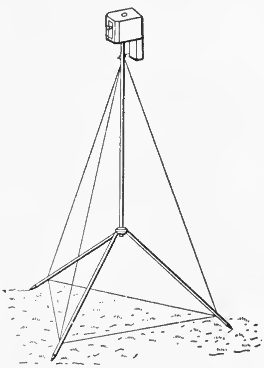


Fig 97

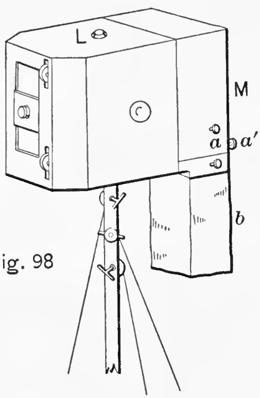


Fig. 98

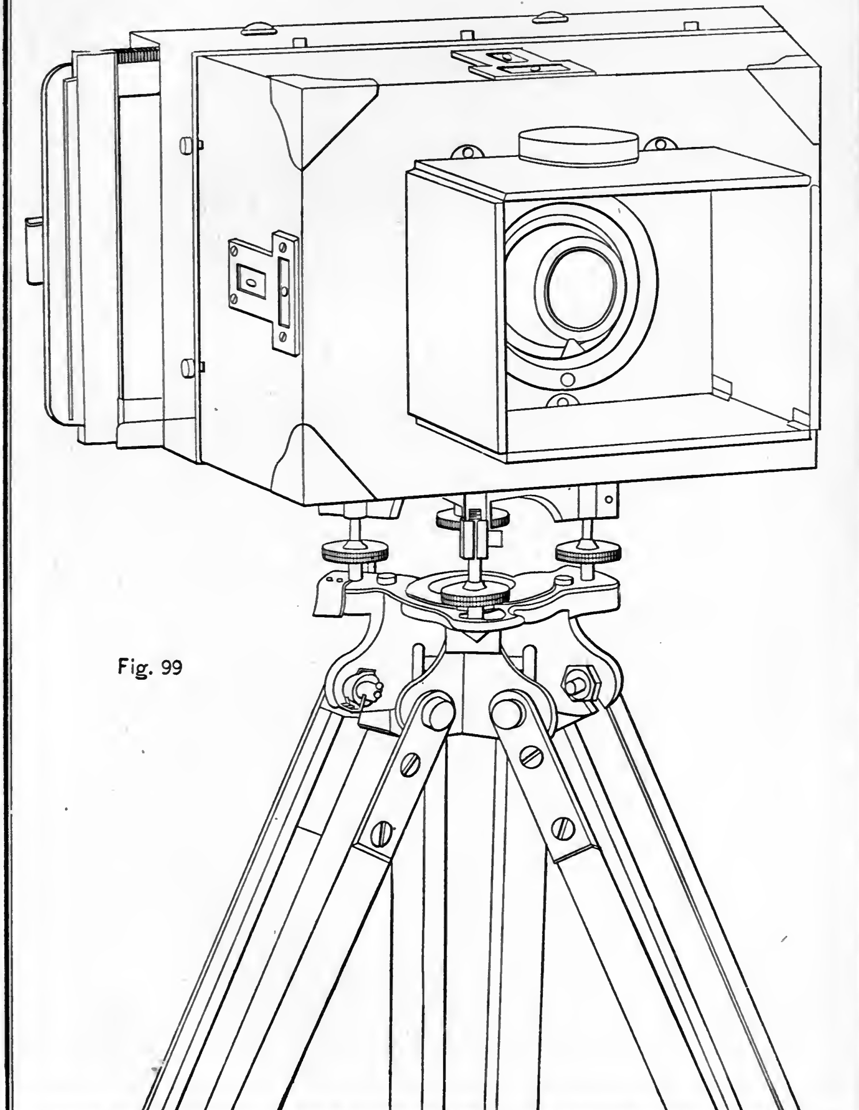


Fig. 99

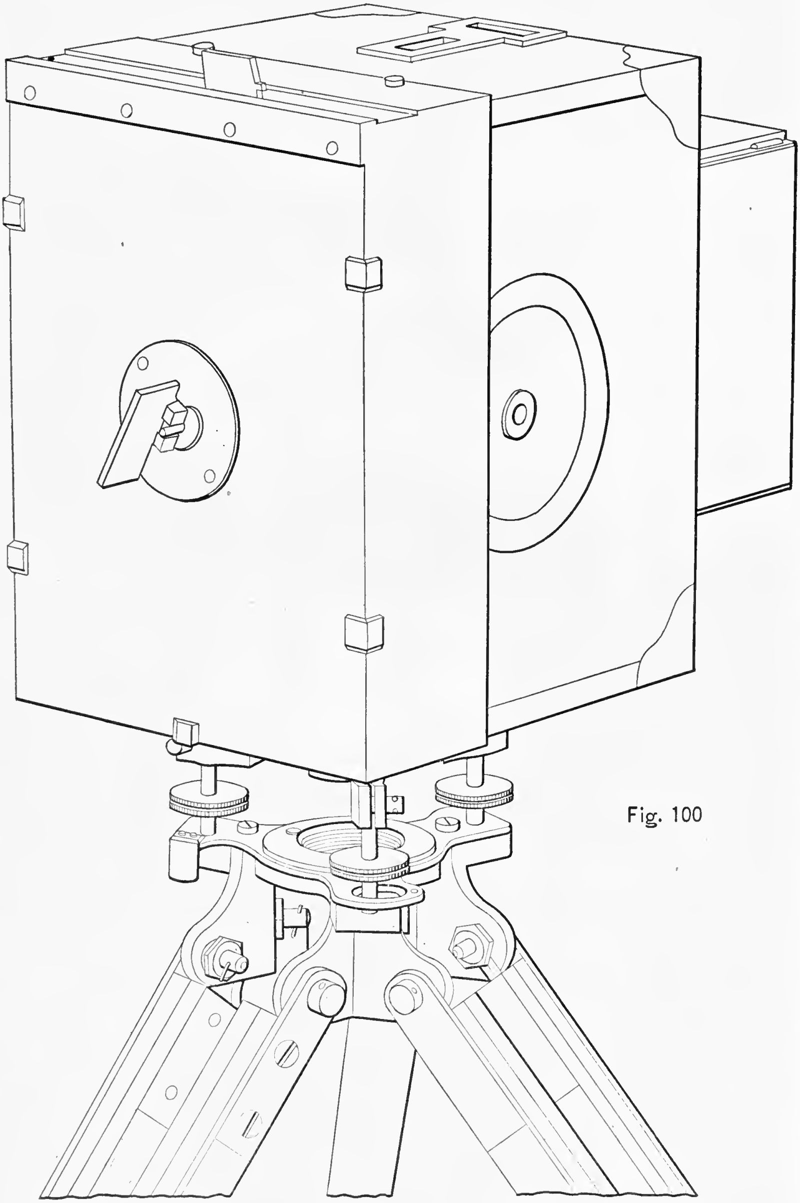


Fig. 100

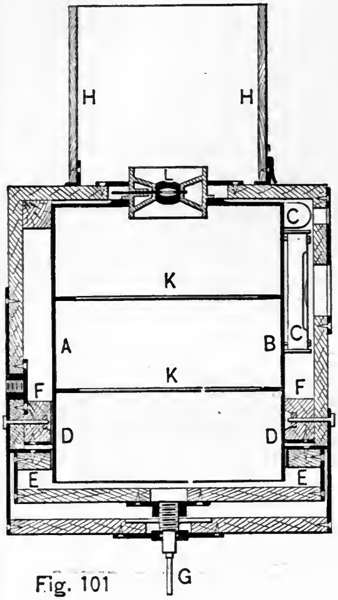


Fig. 101

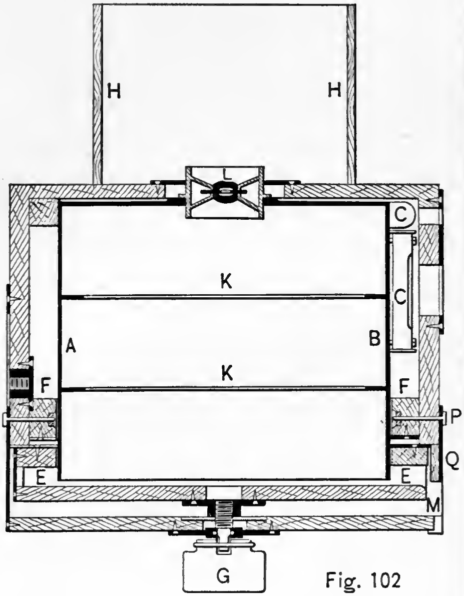


Fig. 102

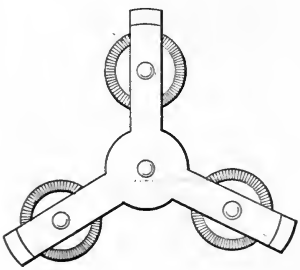


Fig. 103

Fig. 104

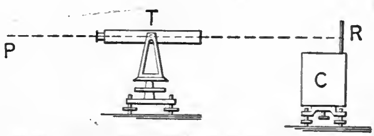


Fig. 105

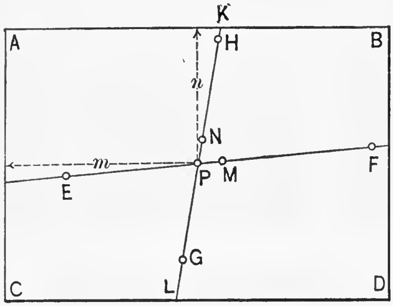


Fig. 106

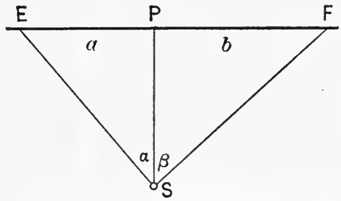


Fig. 107

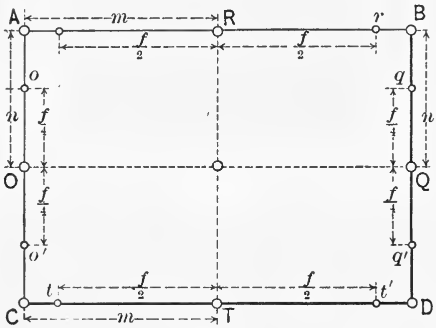


Fig. 108

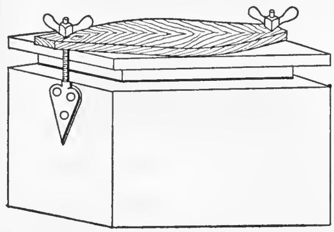
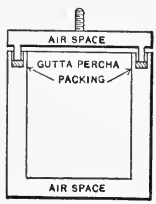


Fig. 110



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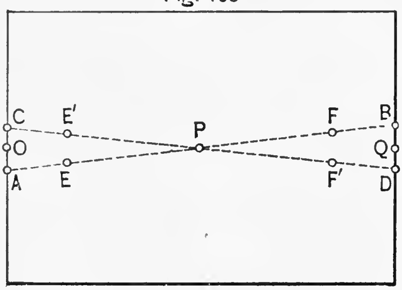

Fig. 109

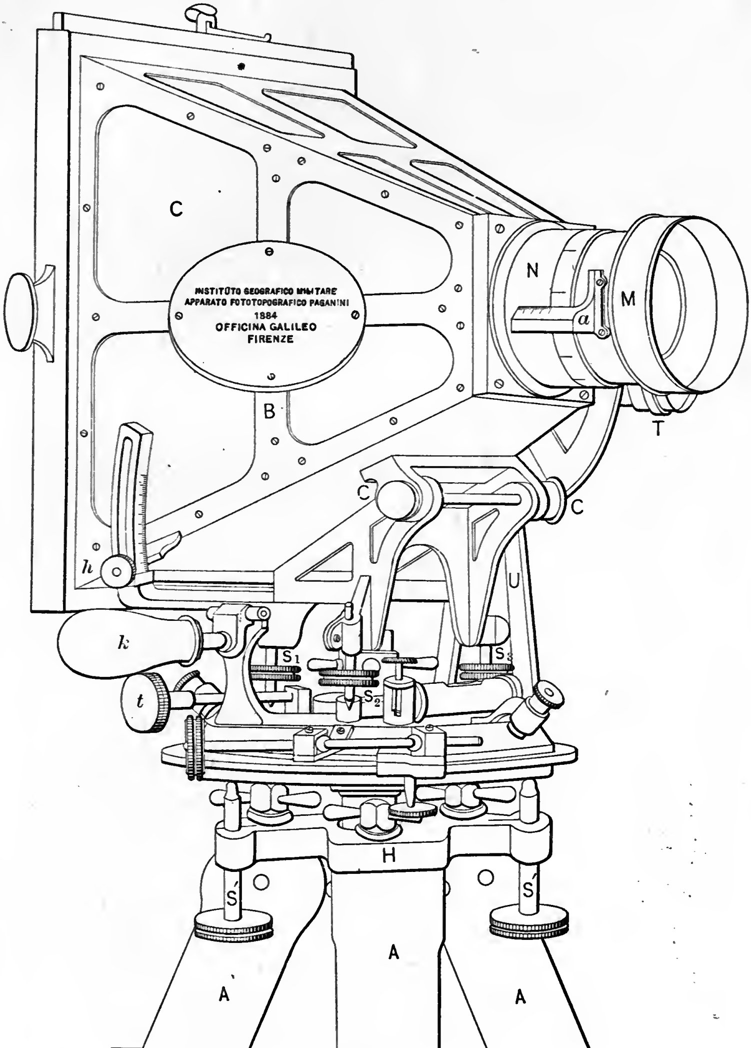
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Fig. 111

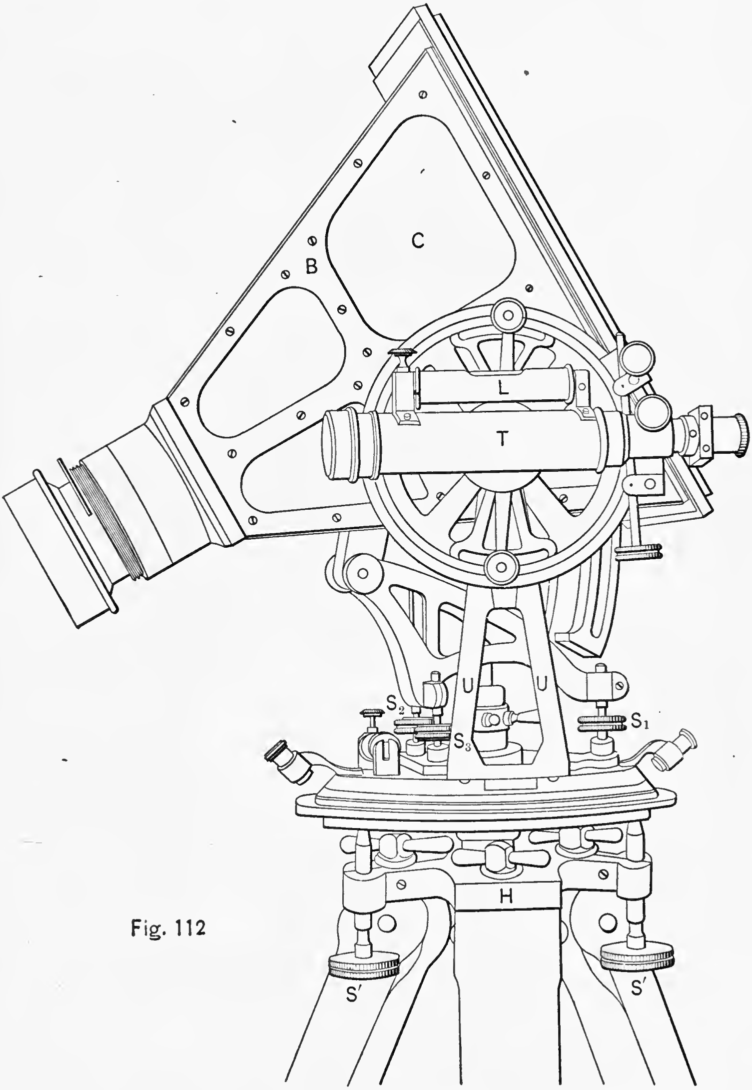

Fig. 112

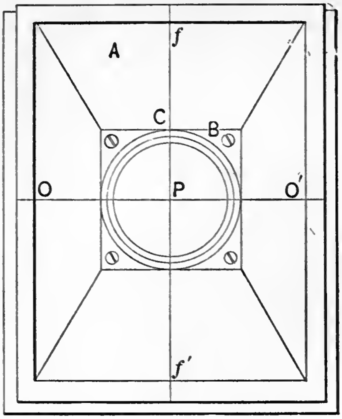

Fig. 113

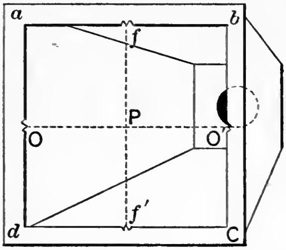

Fig. 114

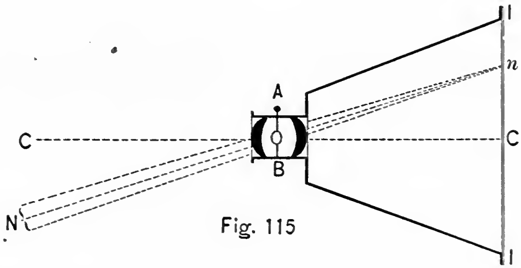

Fig. 115

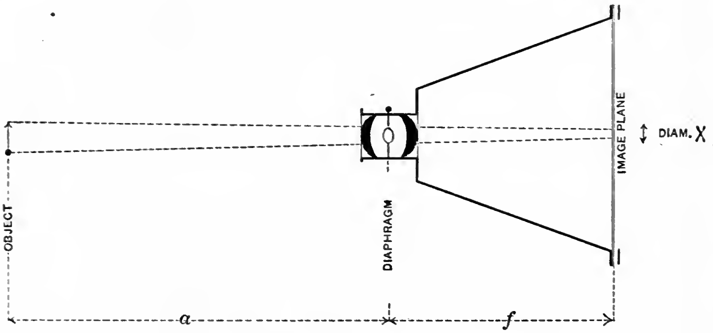

Fig. 116

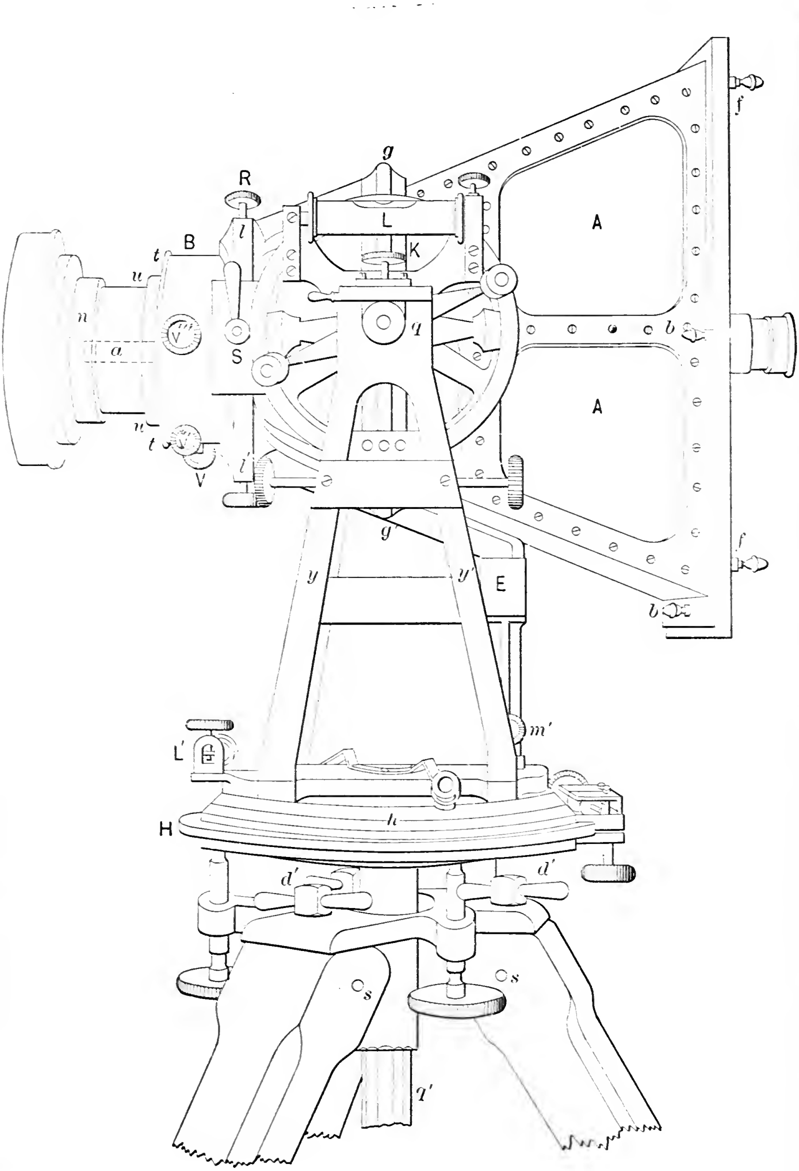

Fig. 117

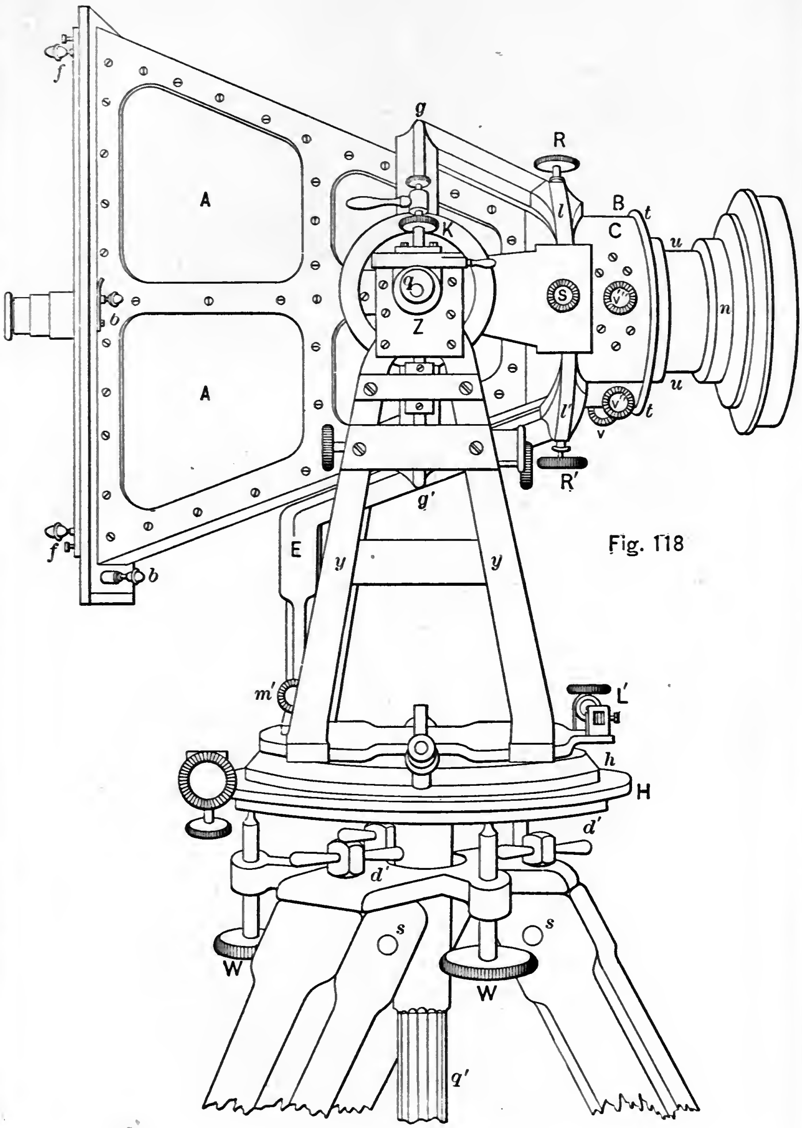

Fig. 118

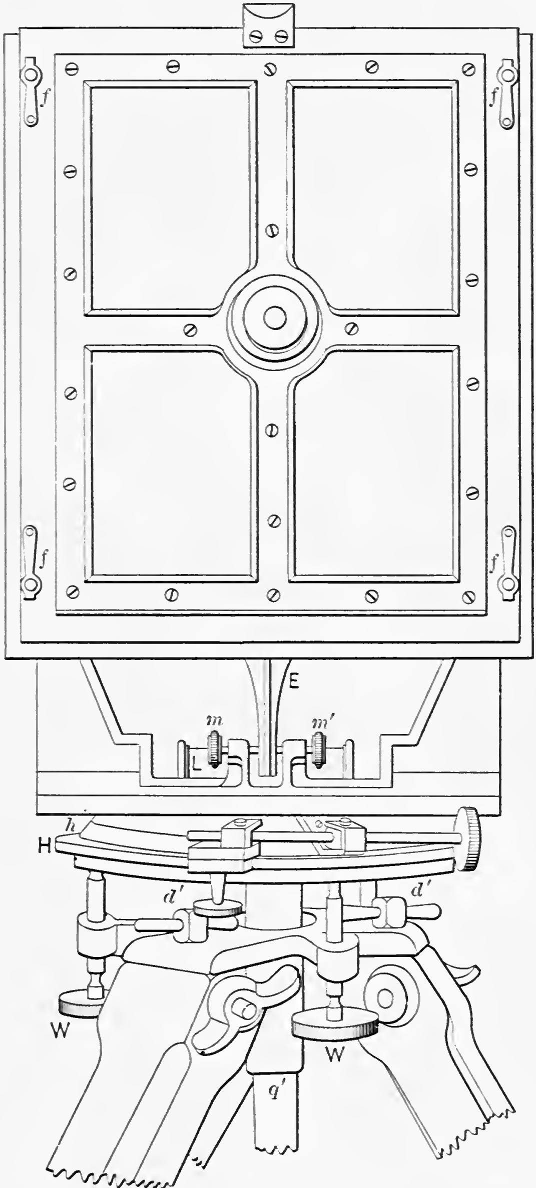

Fig. 119

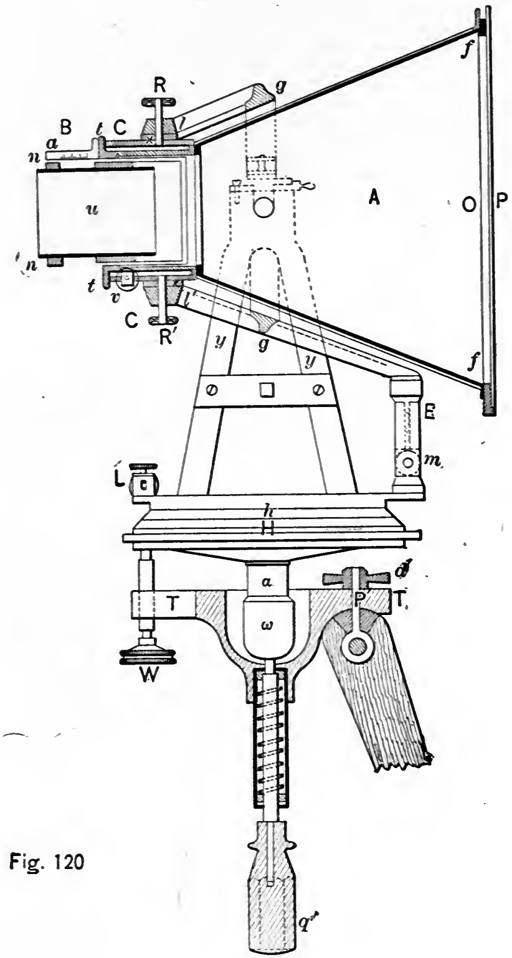

Fig. 120

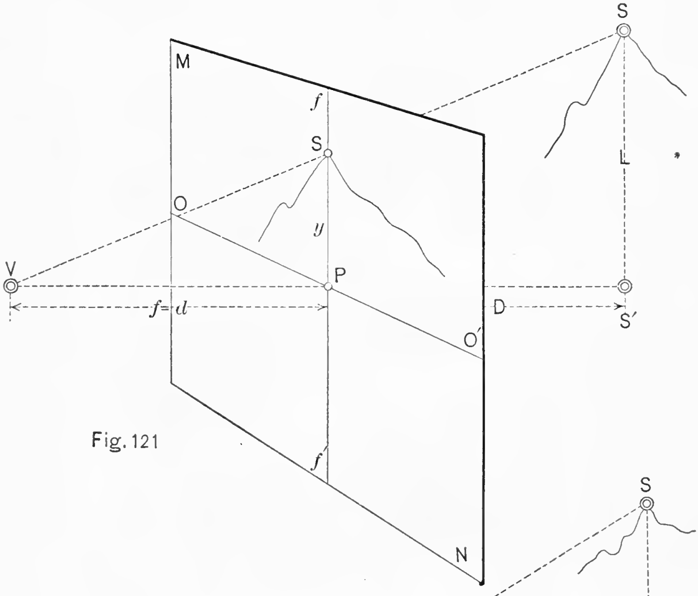

Fig. 121

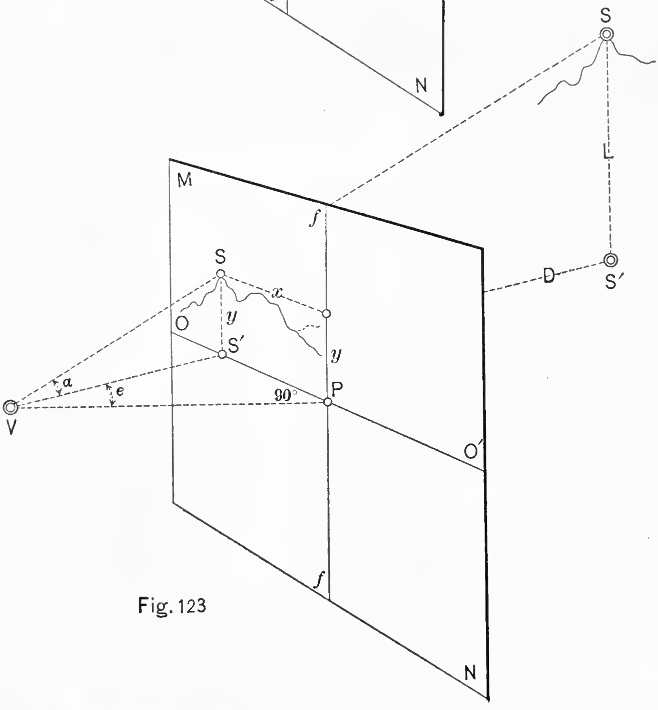

Fig. 123

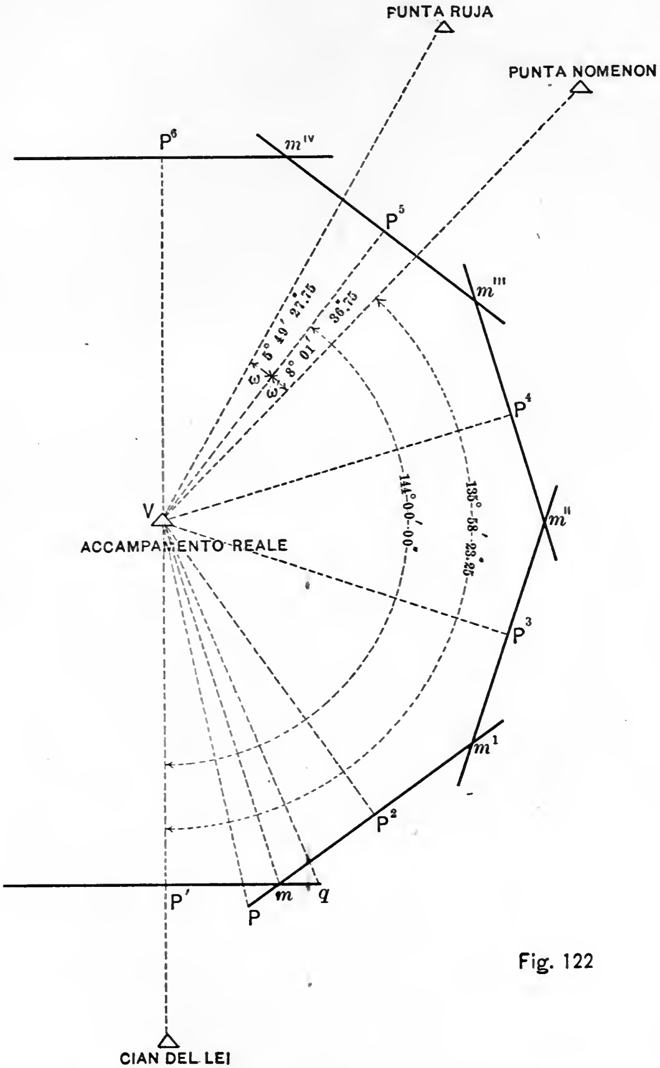
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Fig. 122

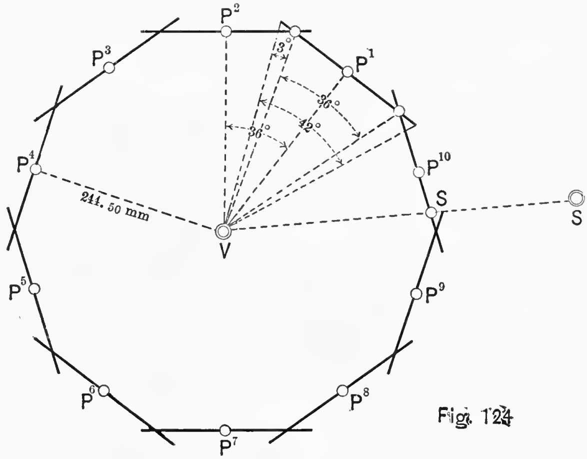

Fig. 124

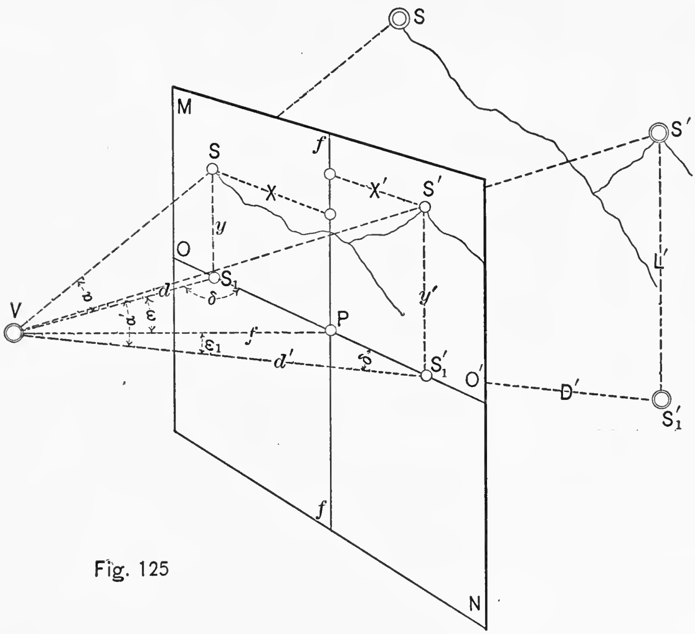

Fig. 125

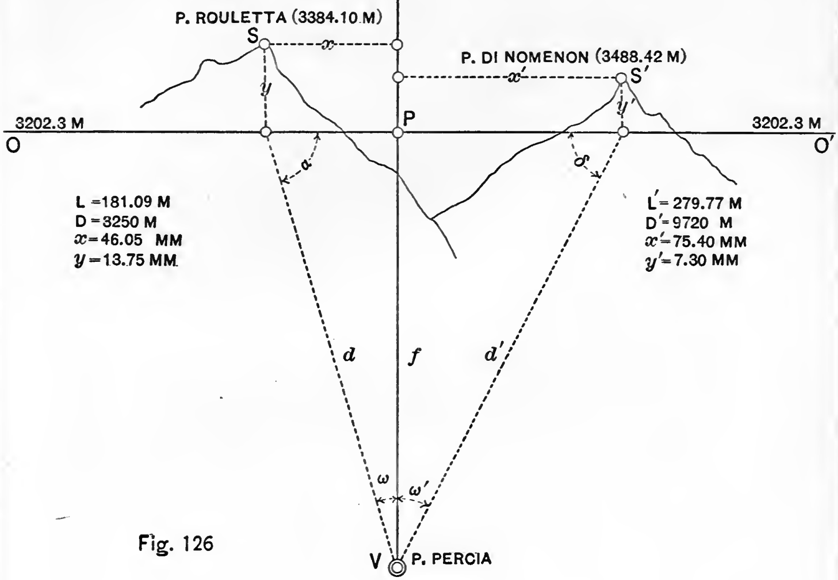

Fig. 126

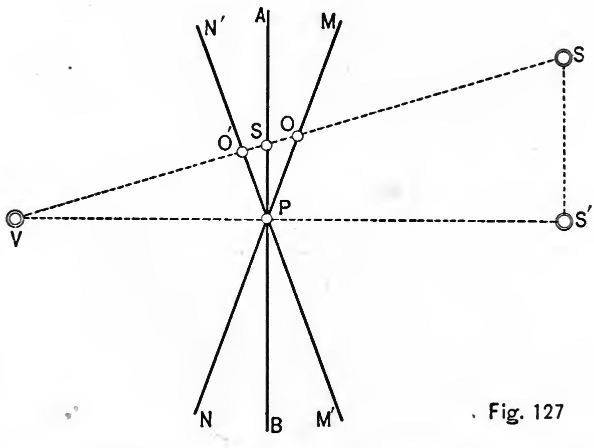

Fig. 127

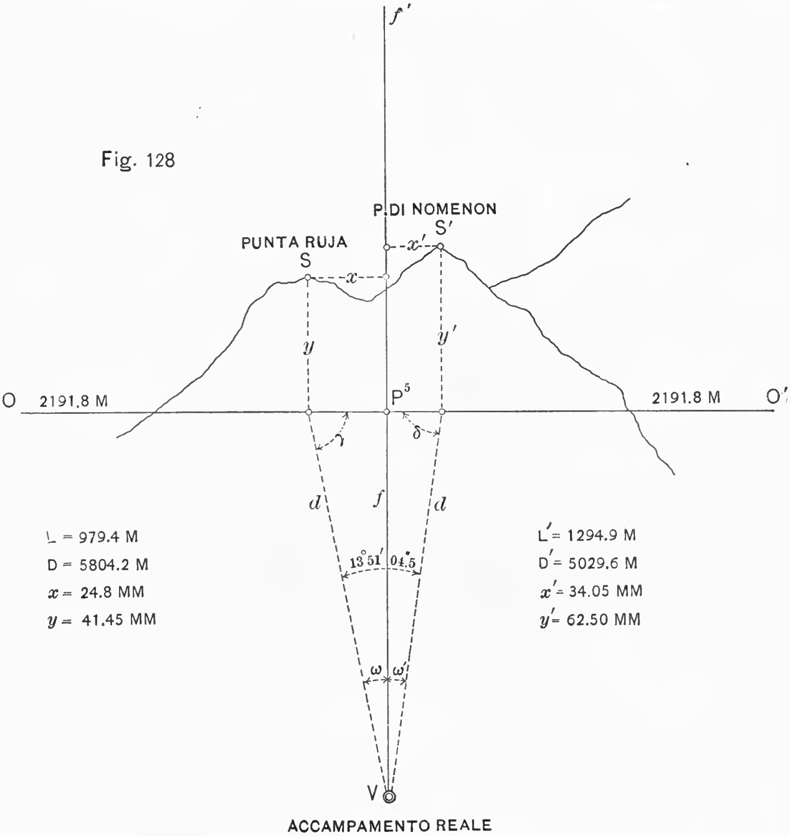

Fig. 128

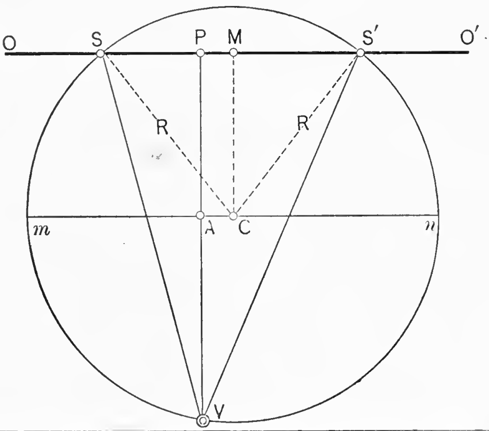

Fig. 129

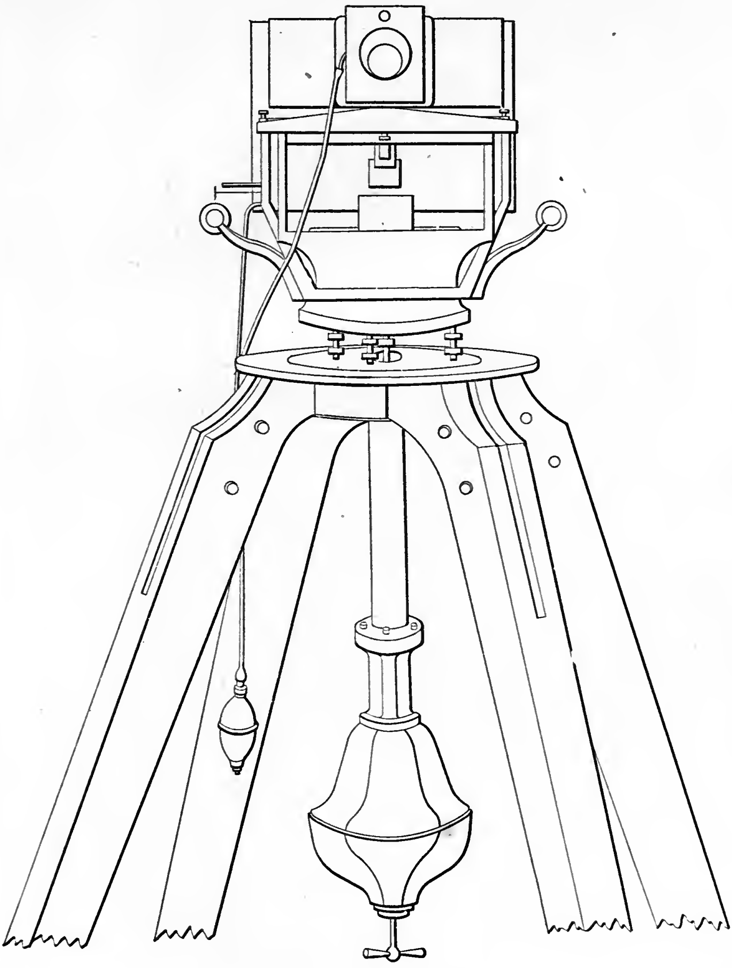

Fig. 130

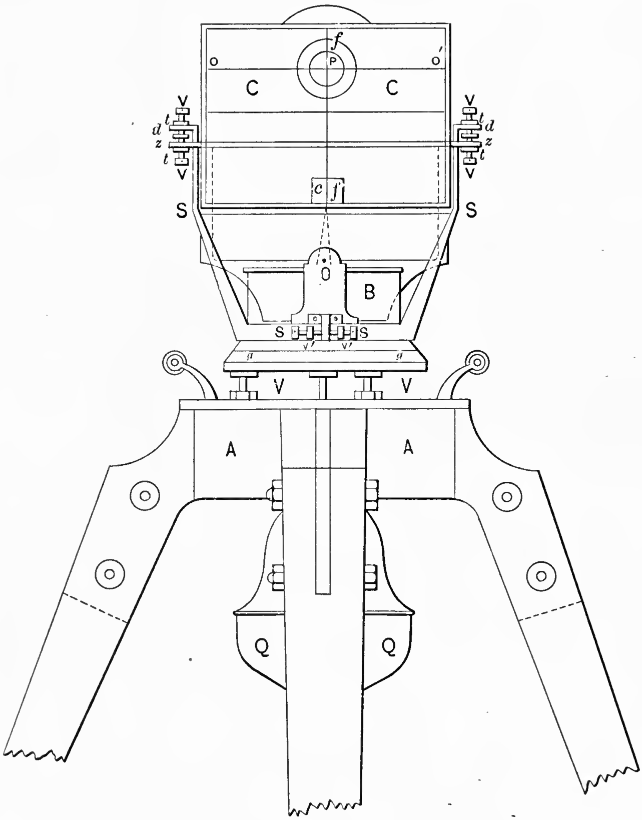

Fig. 131

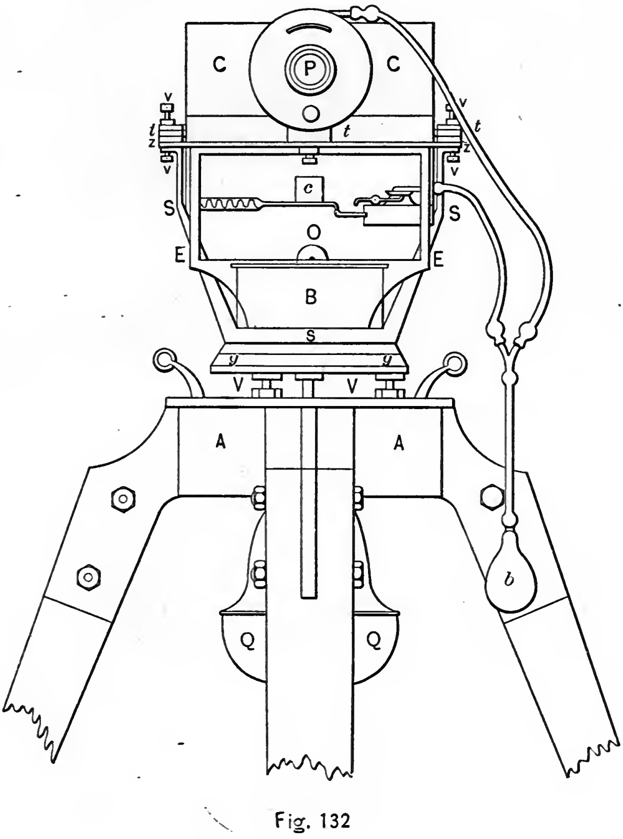

Fig. 132

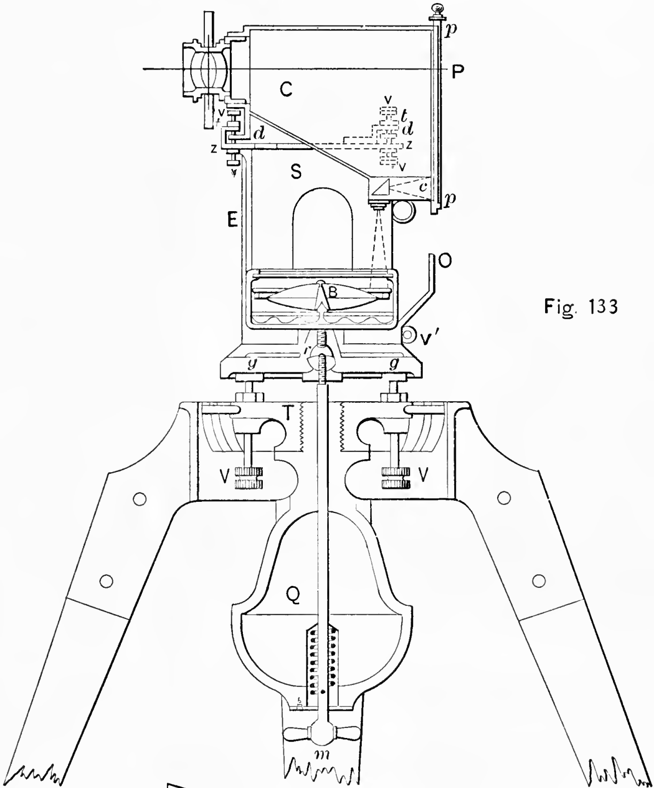

Fig. 133

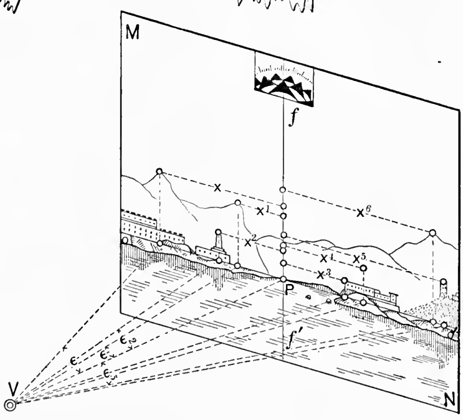

Fig. 134

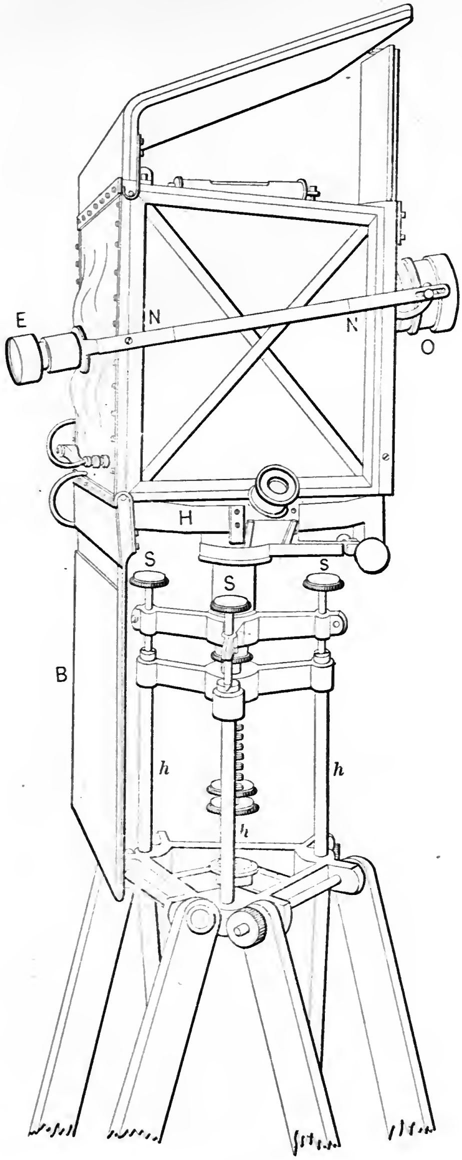

Fig. 135

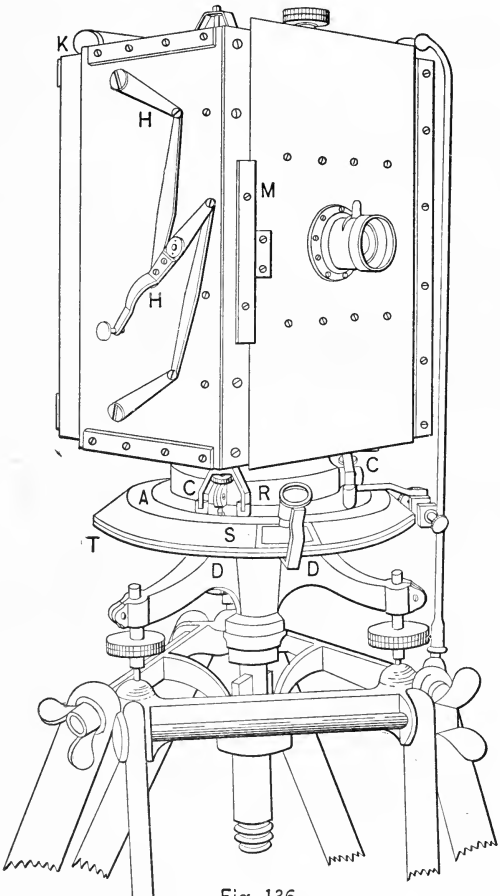

Fig. 136

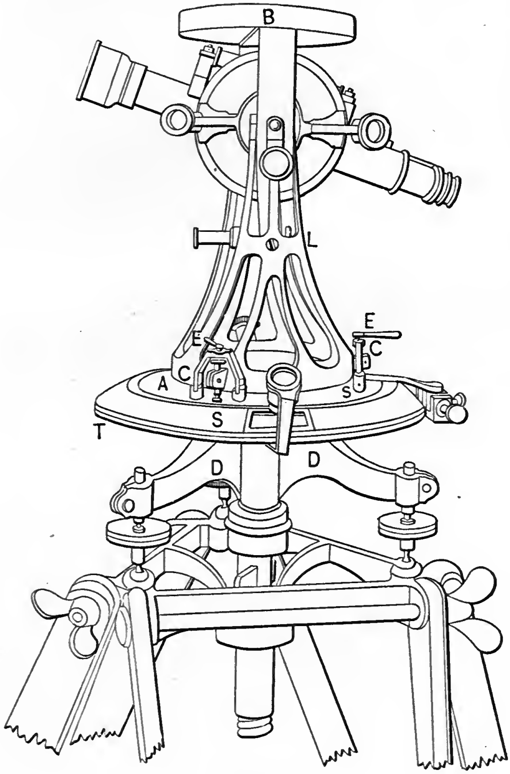

Fig. 137

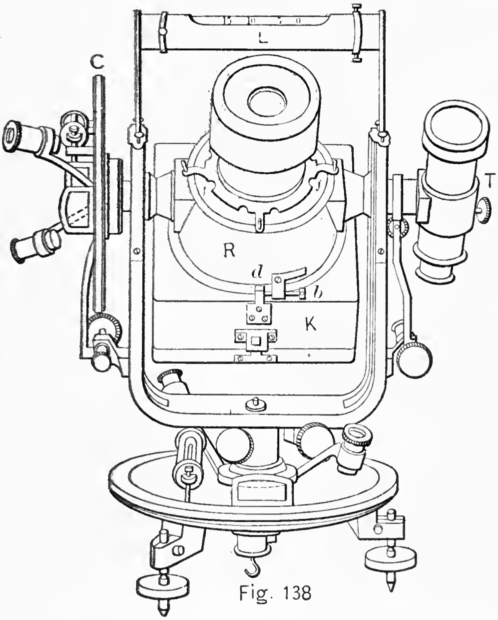

Fig. 138

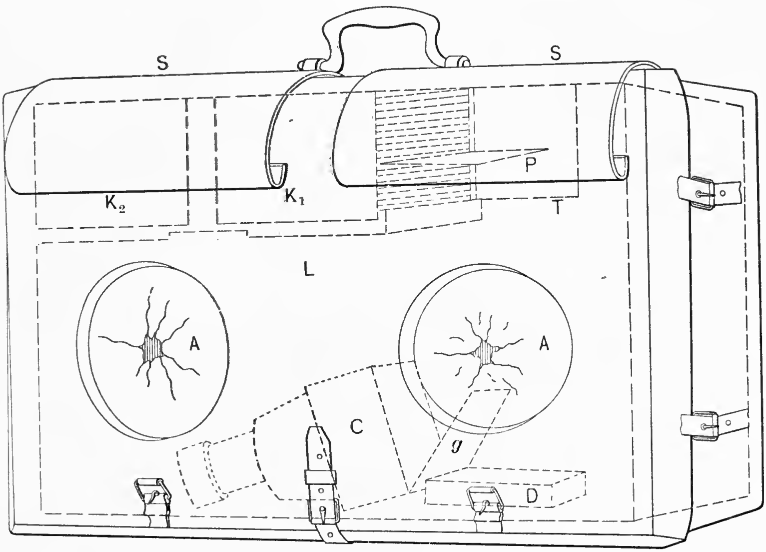

Fig. 139

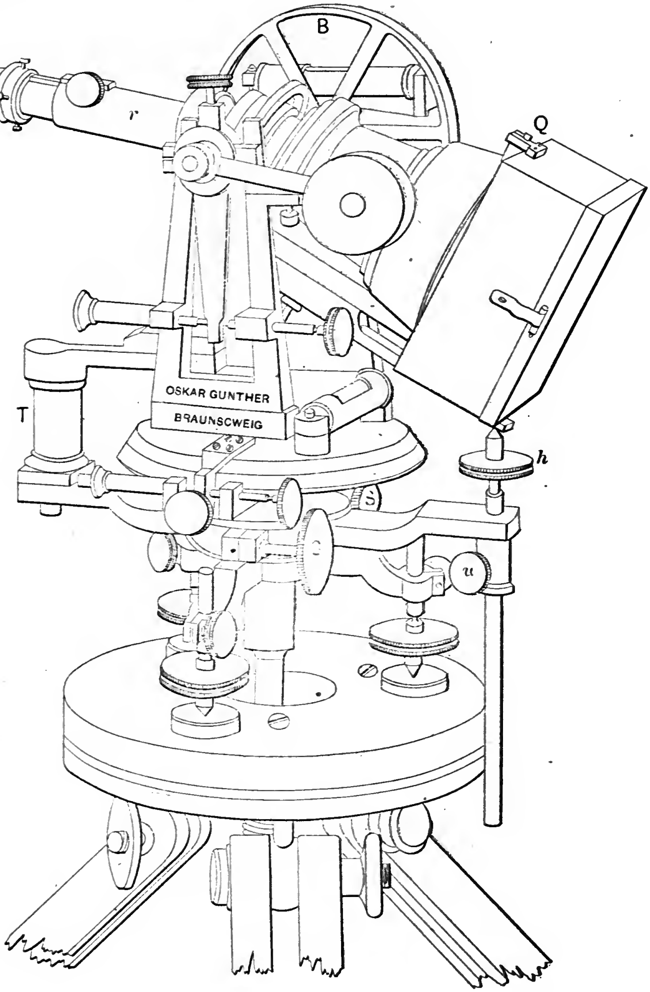

Fig. 140

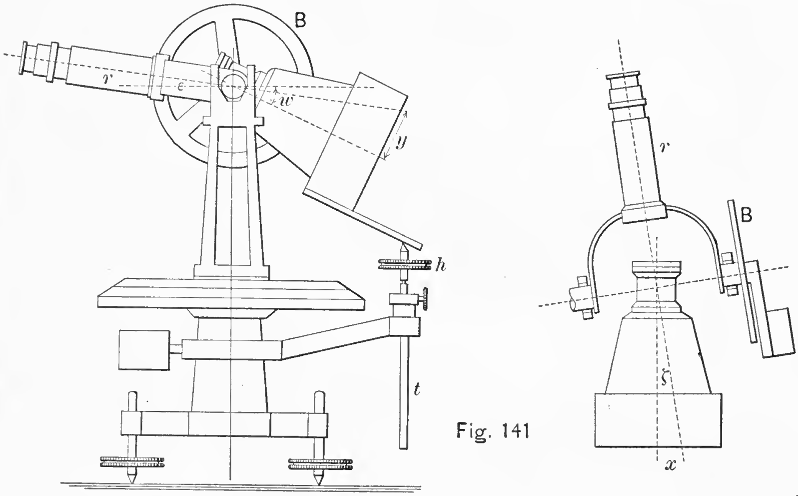

Fig. 141

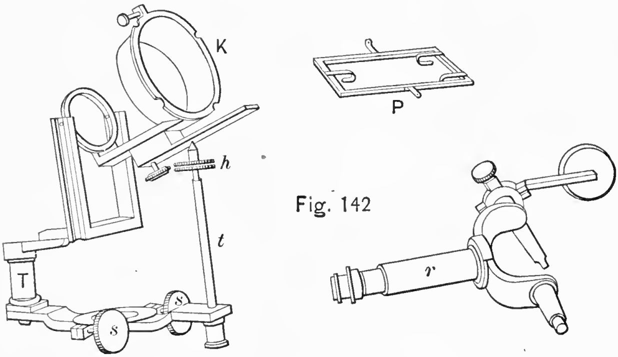

Fig. 142

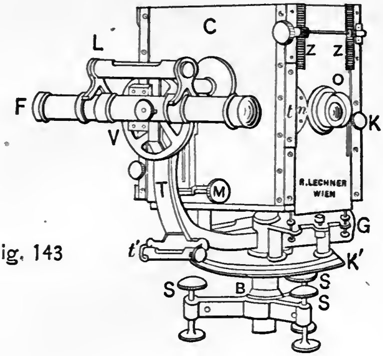

Fig. 143

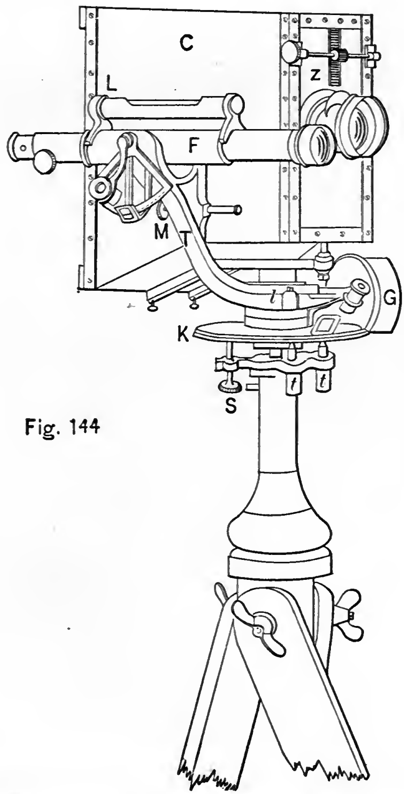

Fig. 144

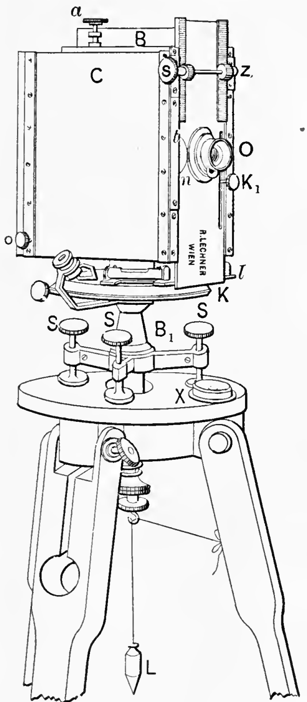

Fig. 145

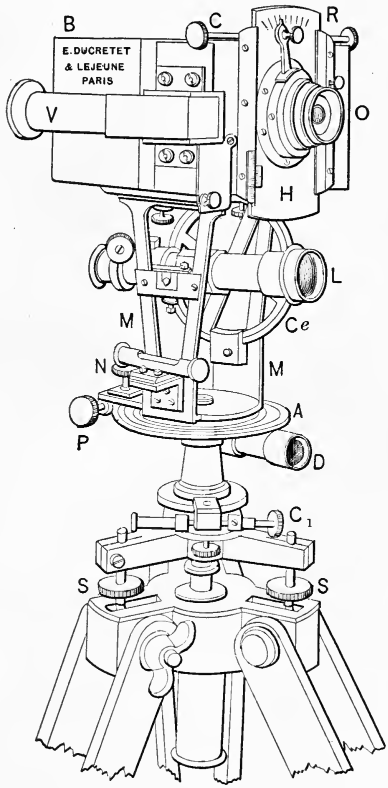

Fig. 146

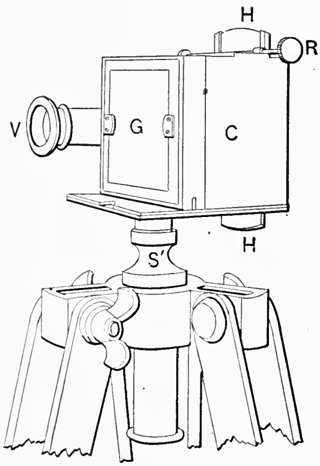

Fig. 147

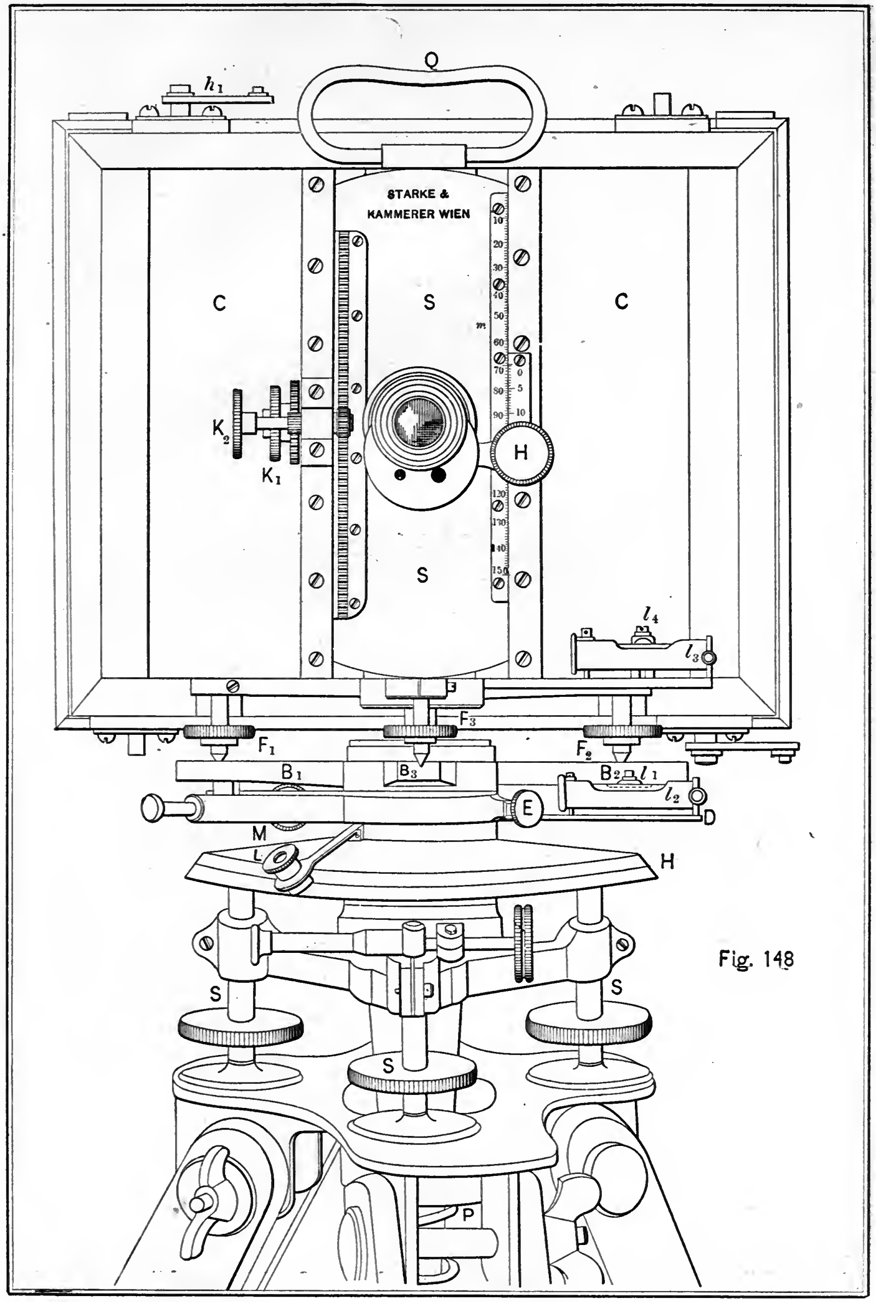
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Fig. 148

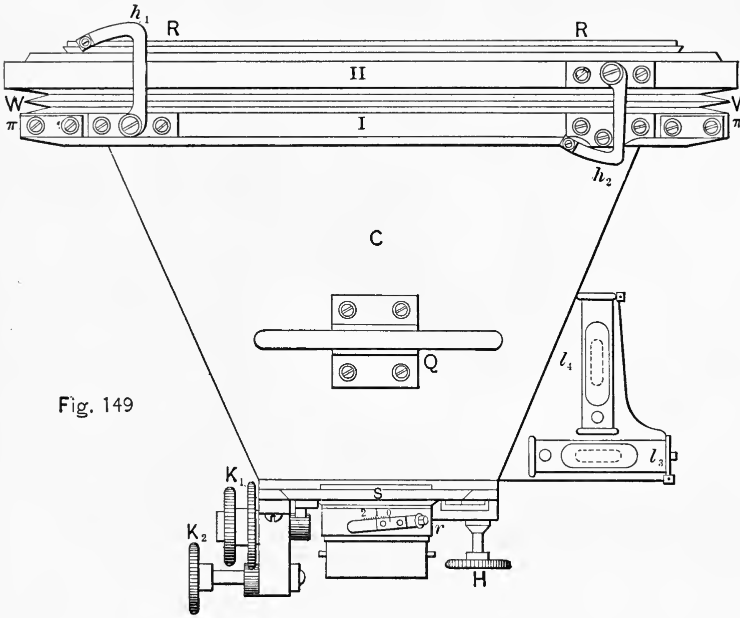


Fig. 149

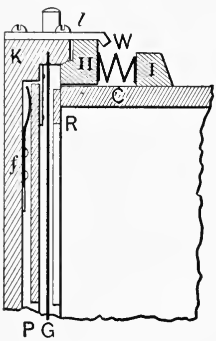


Fig. 150

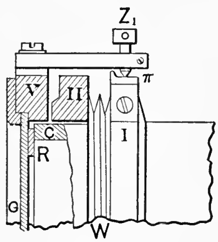
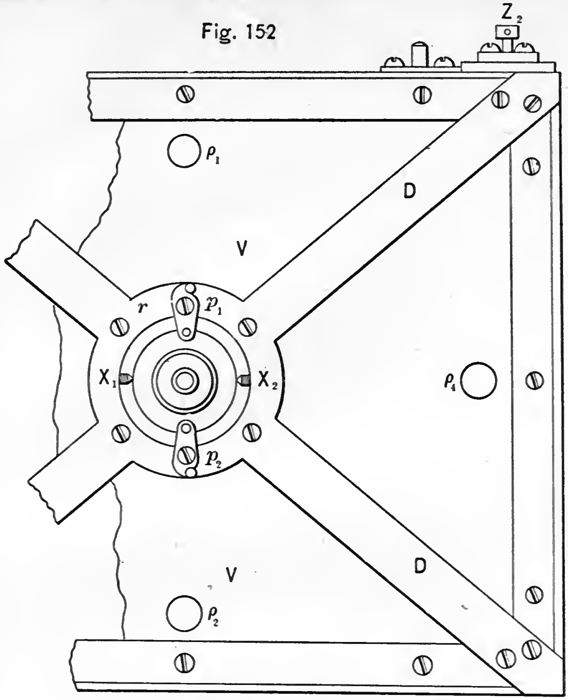


Fig. 151

Fig. 152



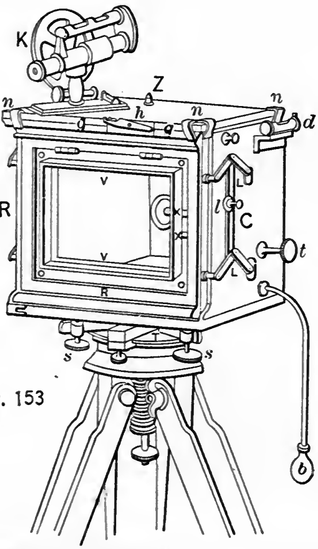


Fig. 153

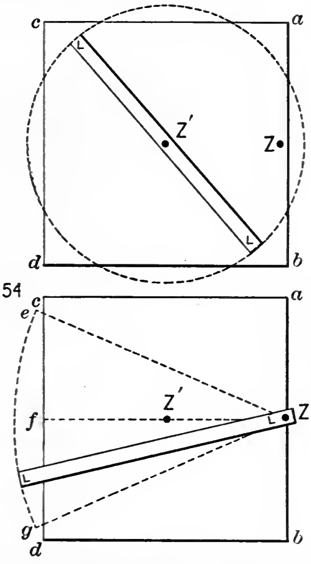


Fig. 154

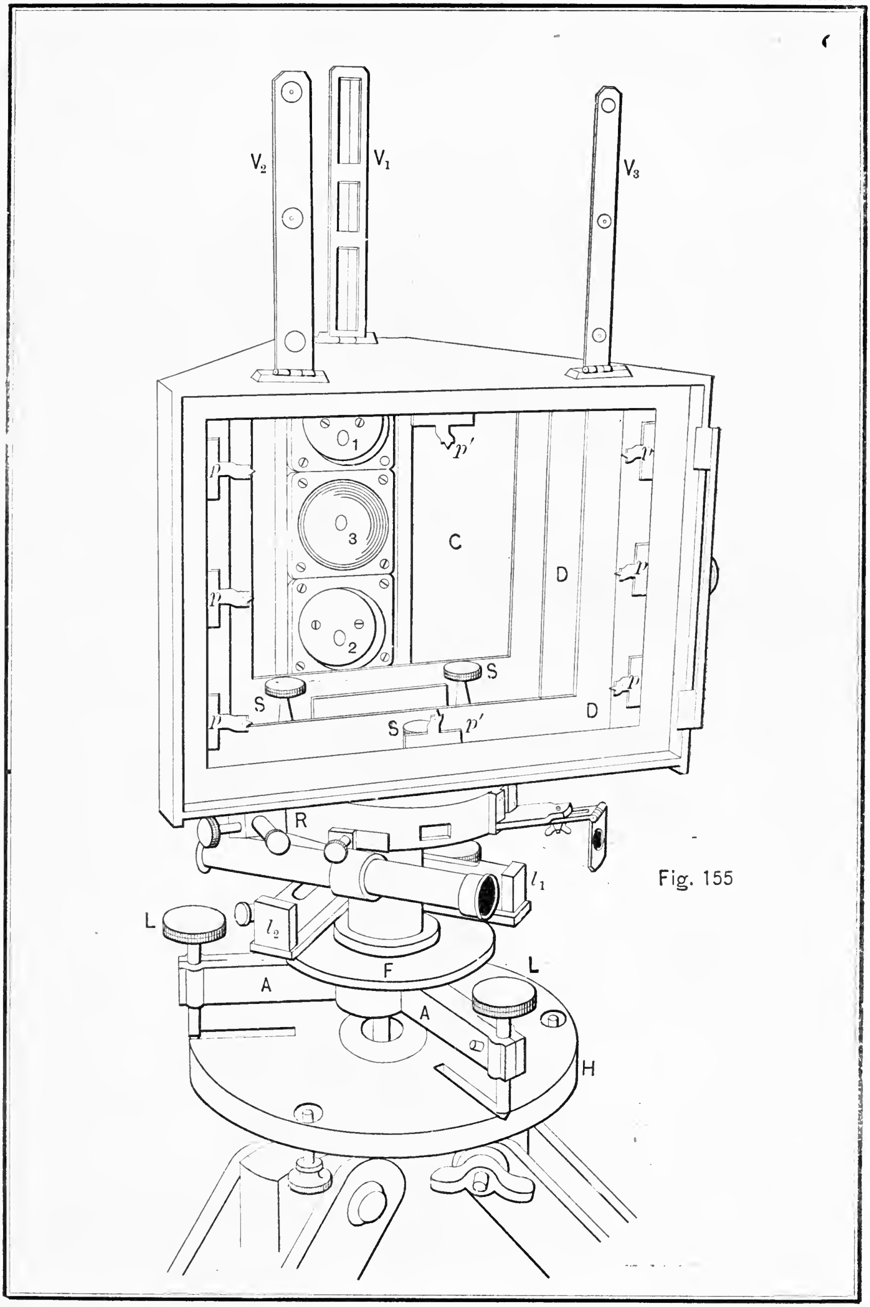


Fig. 155

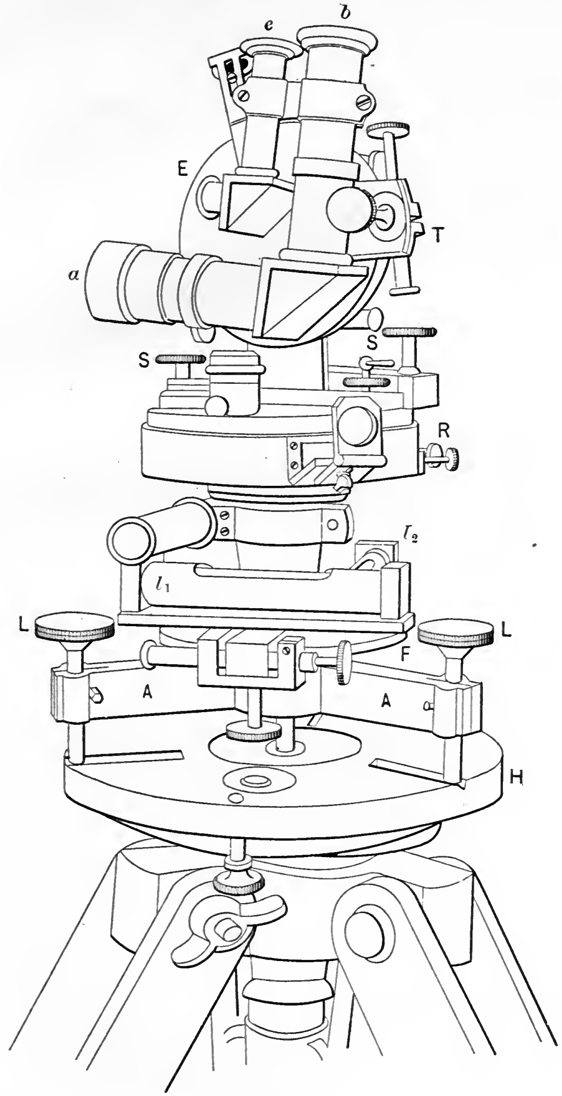


Fig. 156

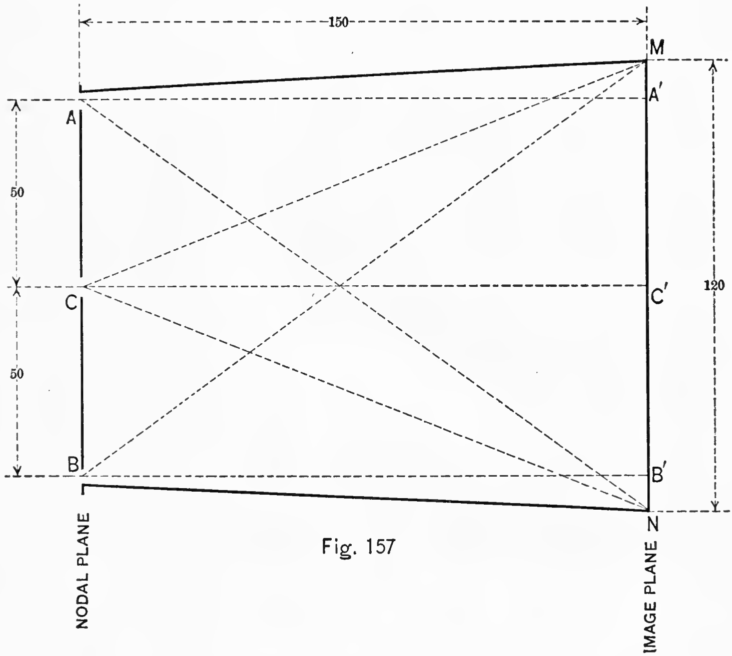


Fig. 157

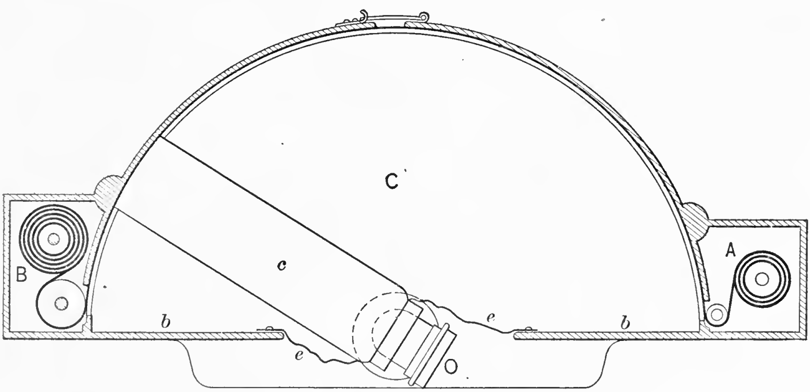


Fig. 160

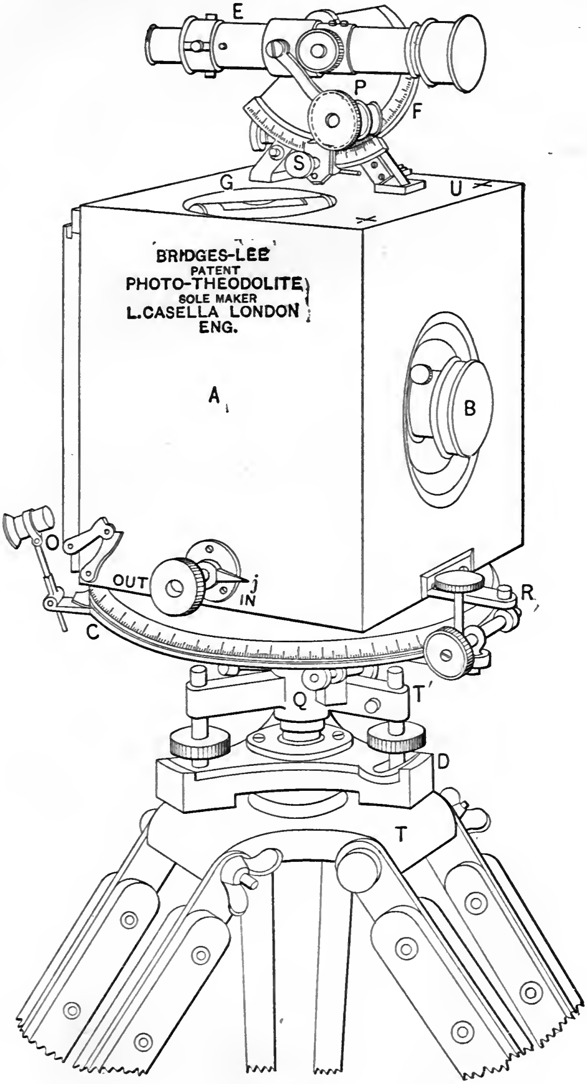

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Fig. 158

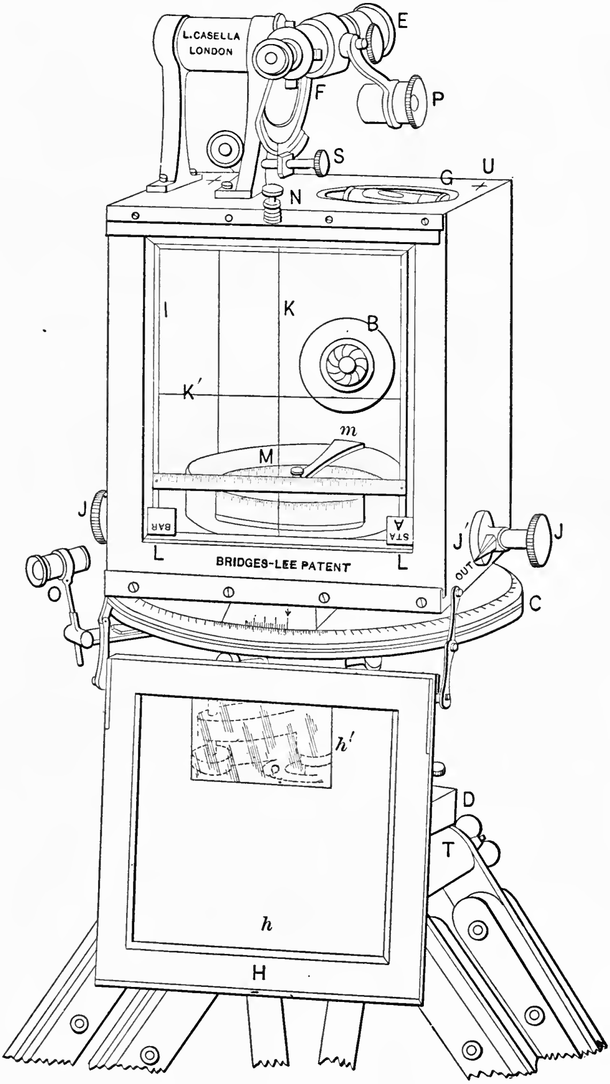
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Fig. 159

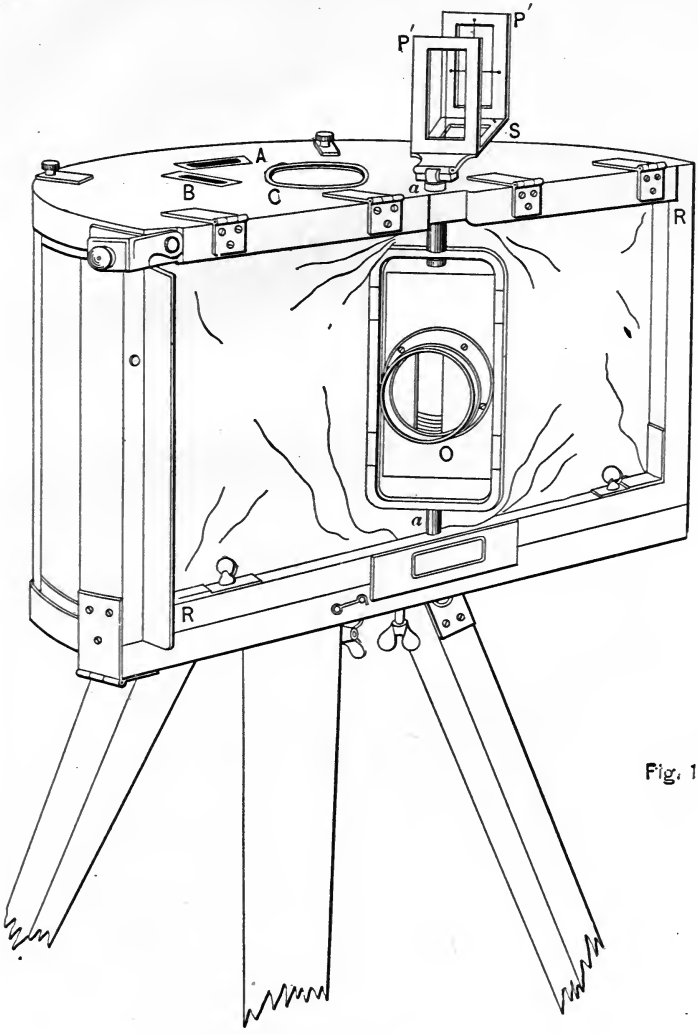


Fig. 161

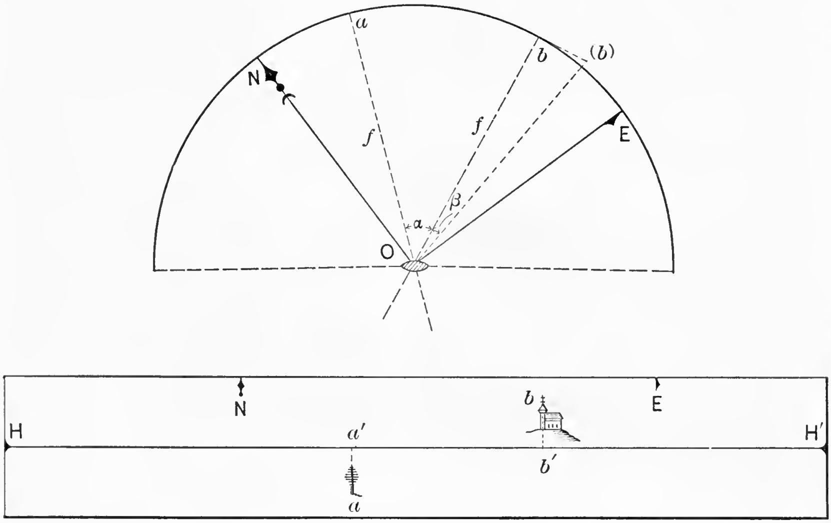


Fig. 162

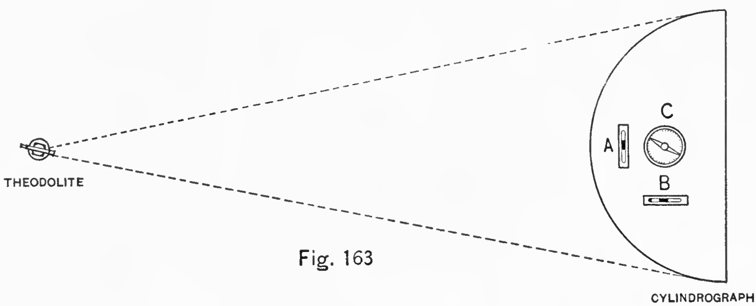


Fig. 163

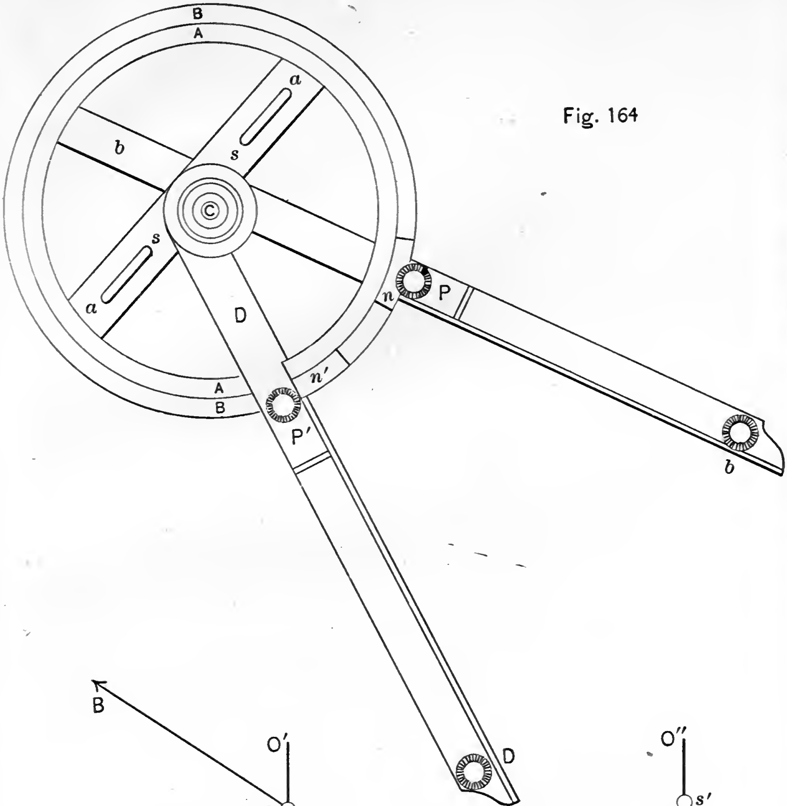


Fig. 164

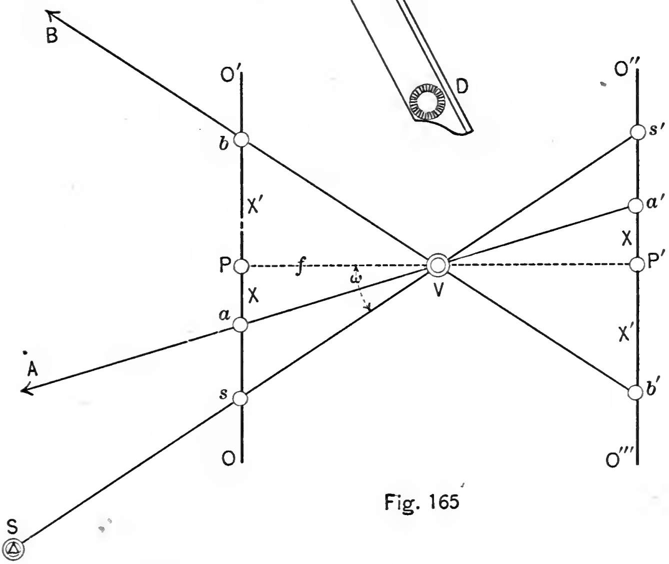


Fig. 165

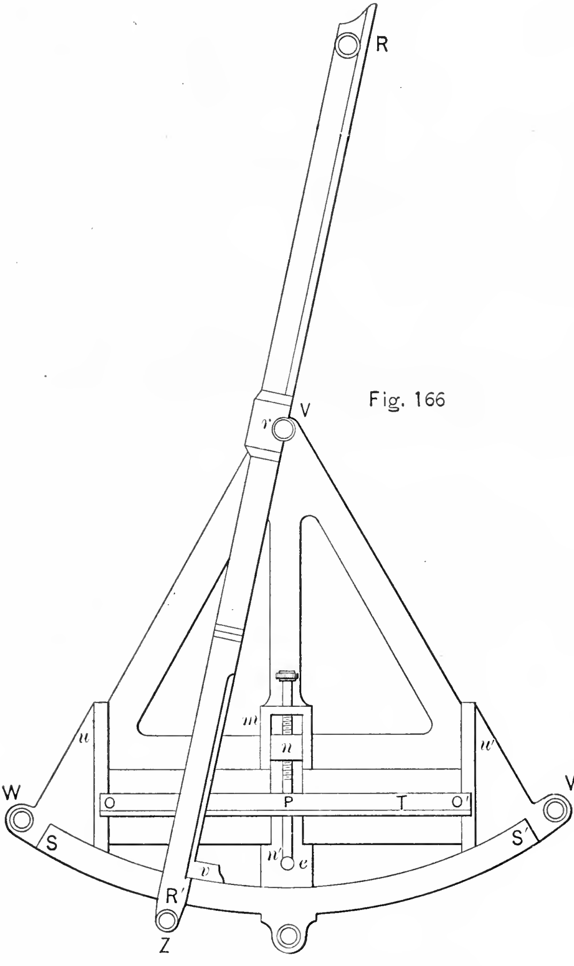


Fig. 166

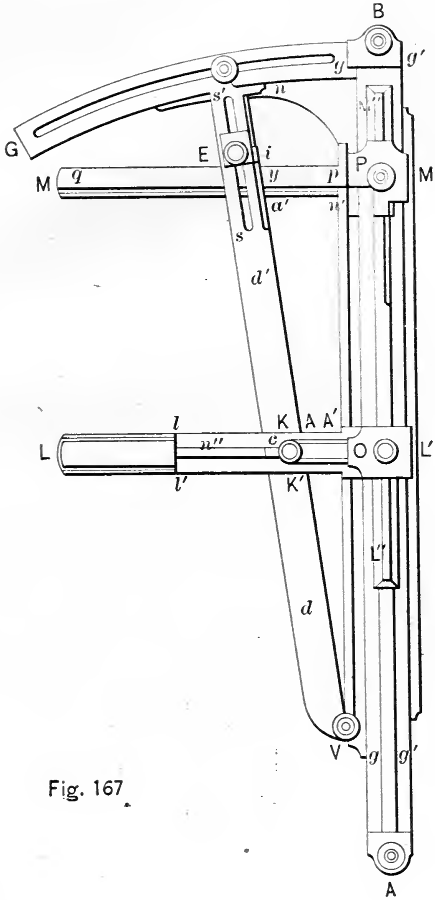


Fig. 167

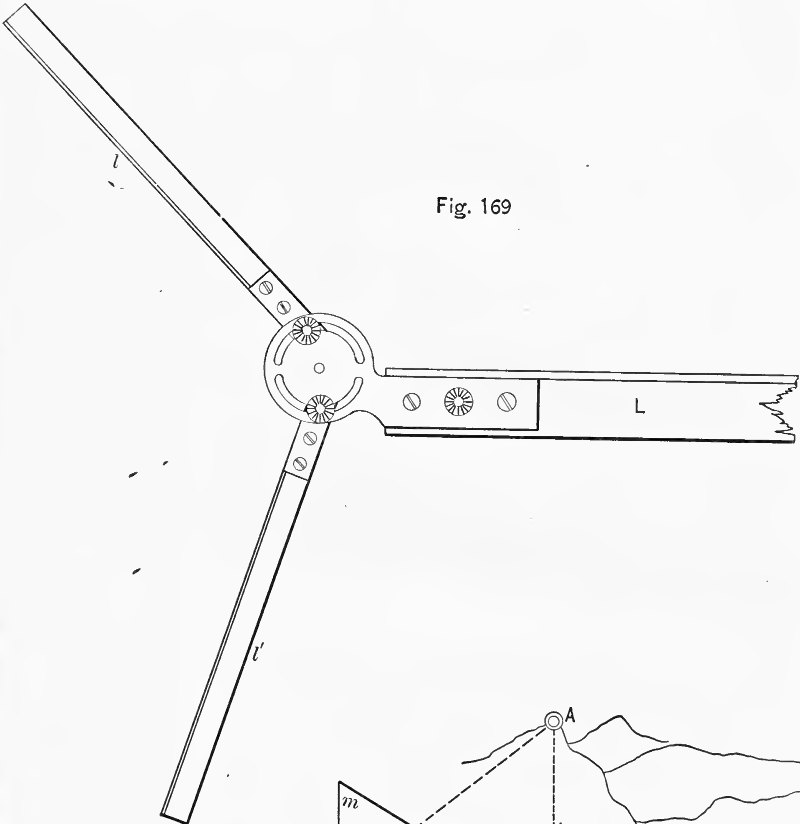


Fig. 169

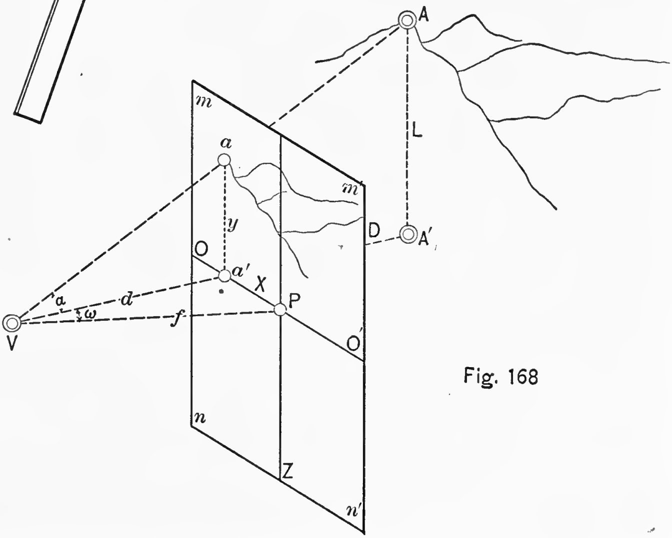


Fig. 168

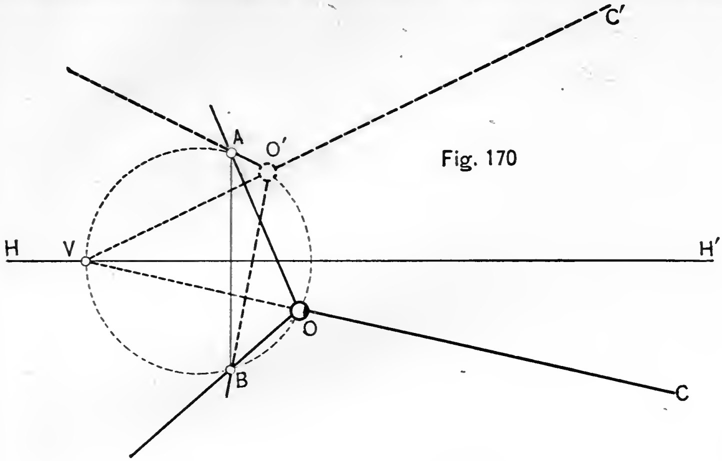


Fig. 170

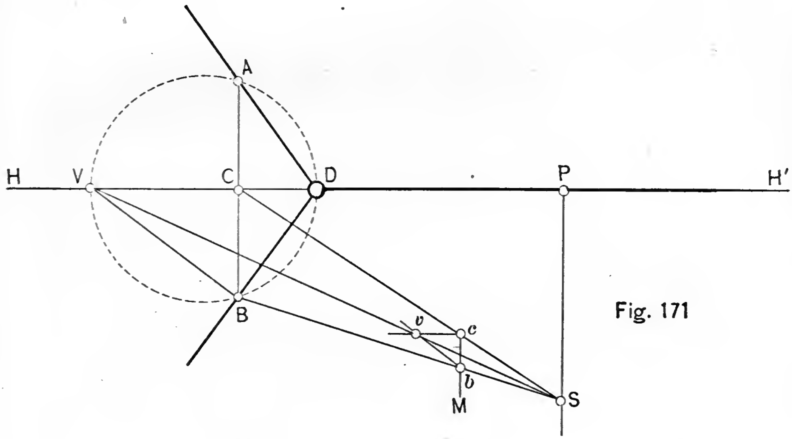


Fig. 171

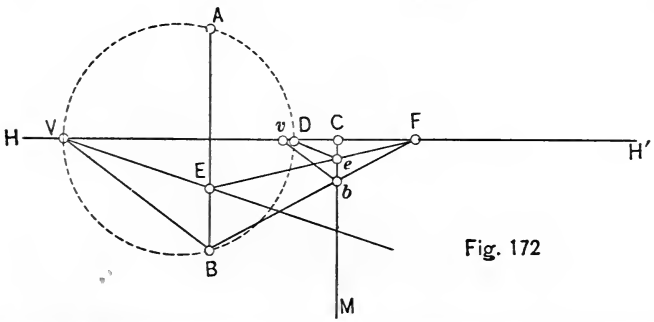


Fig. 172

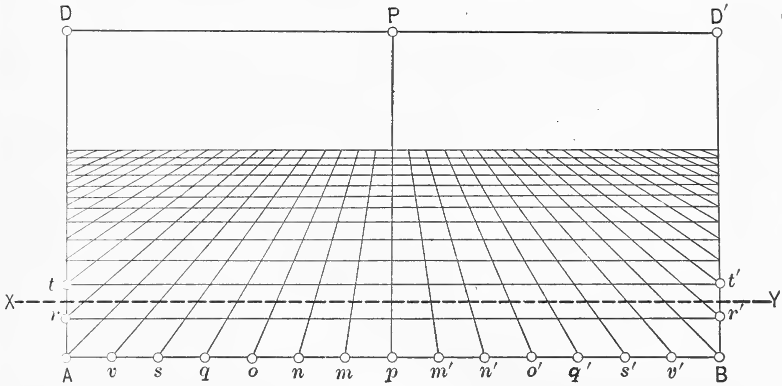


Fig. 173

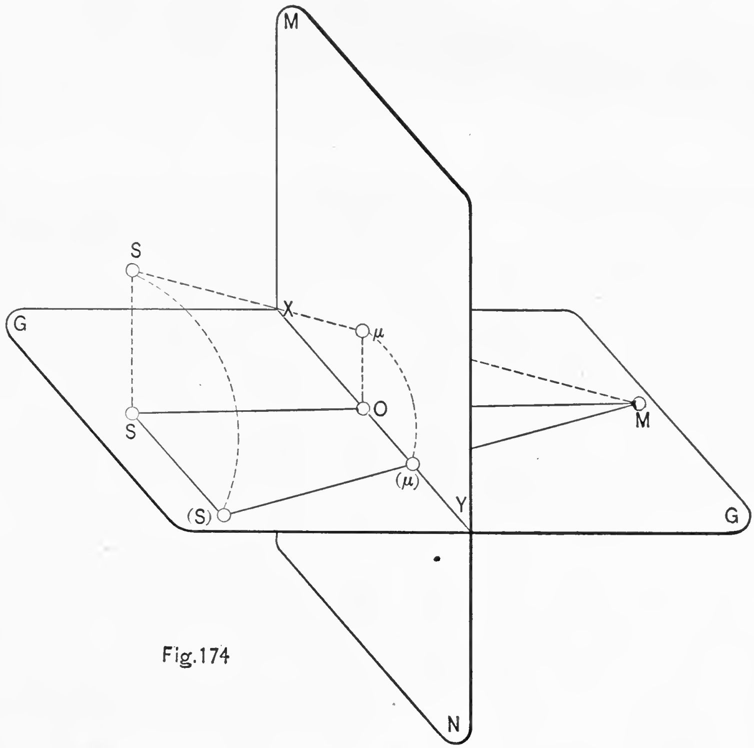


Fig. 174

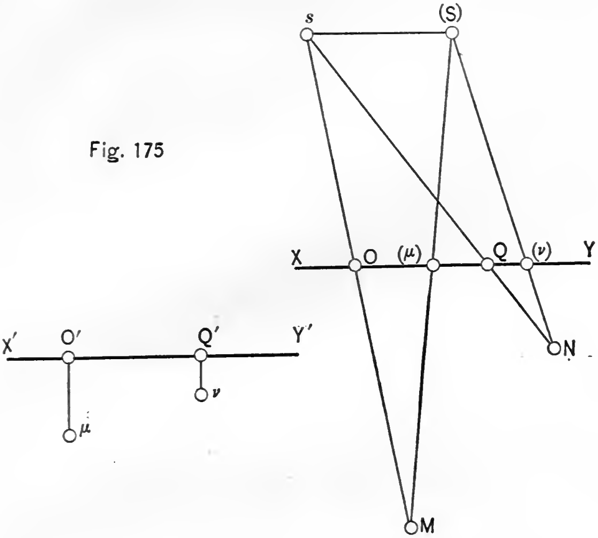


Fig. 175

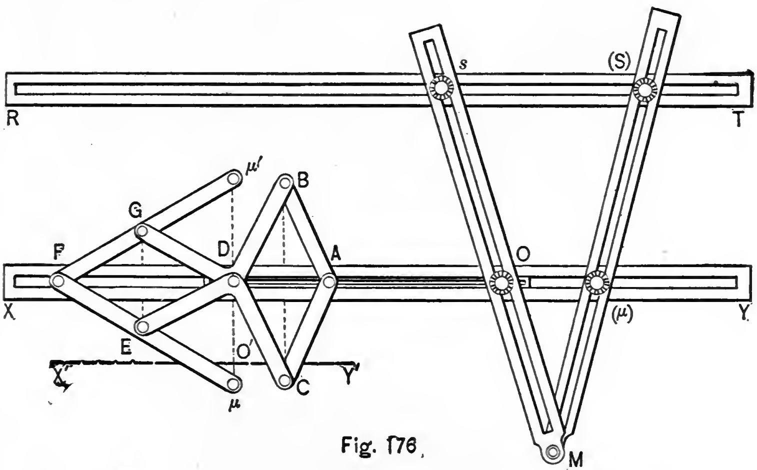


Fig. 176

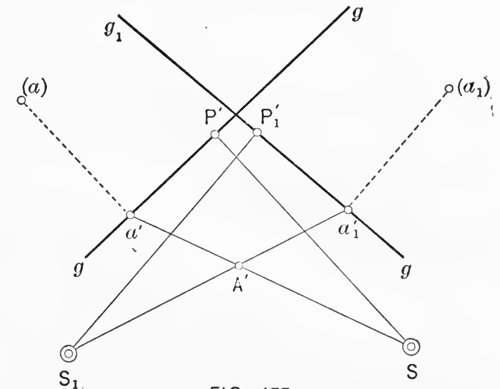


FIG. 177

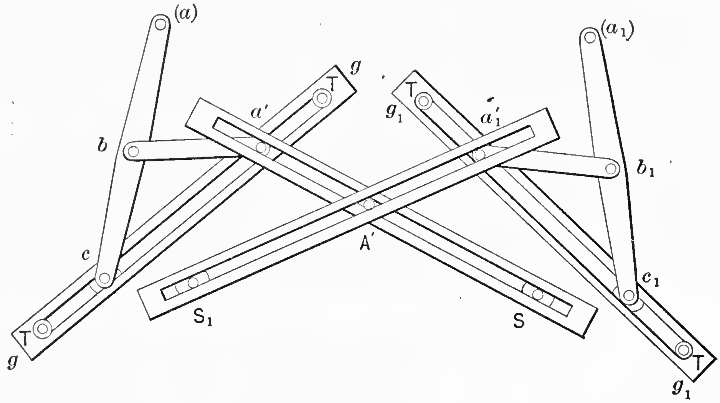


FIG. 178

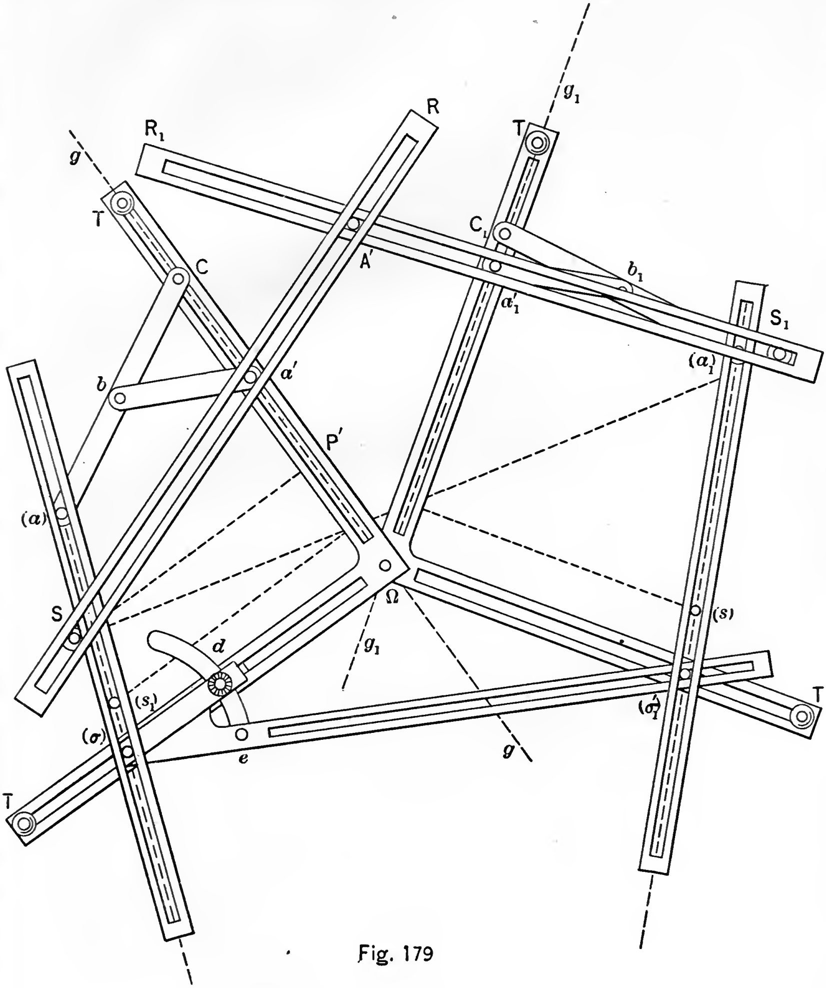
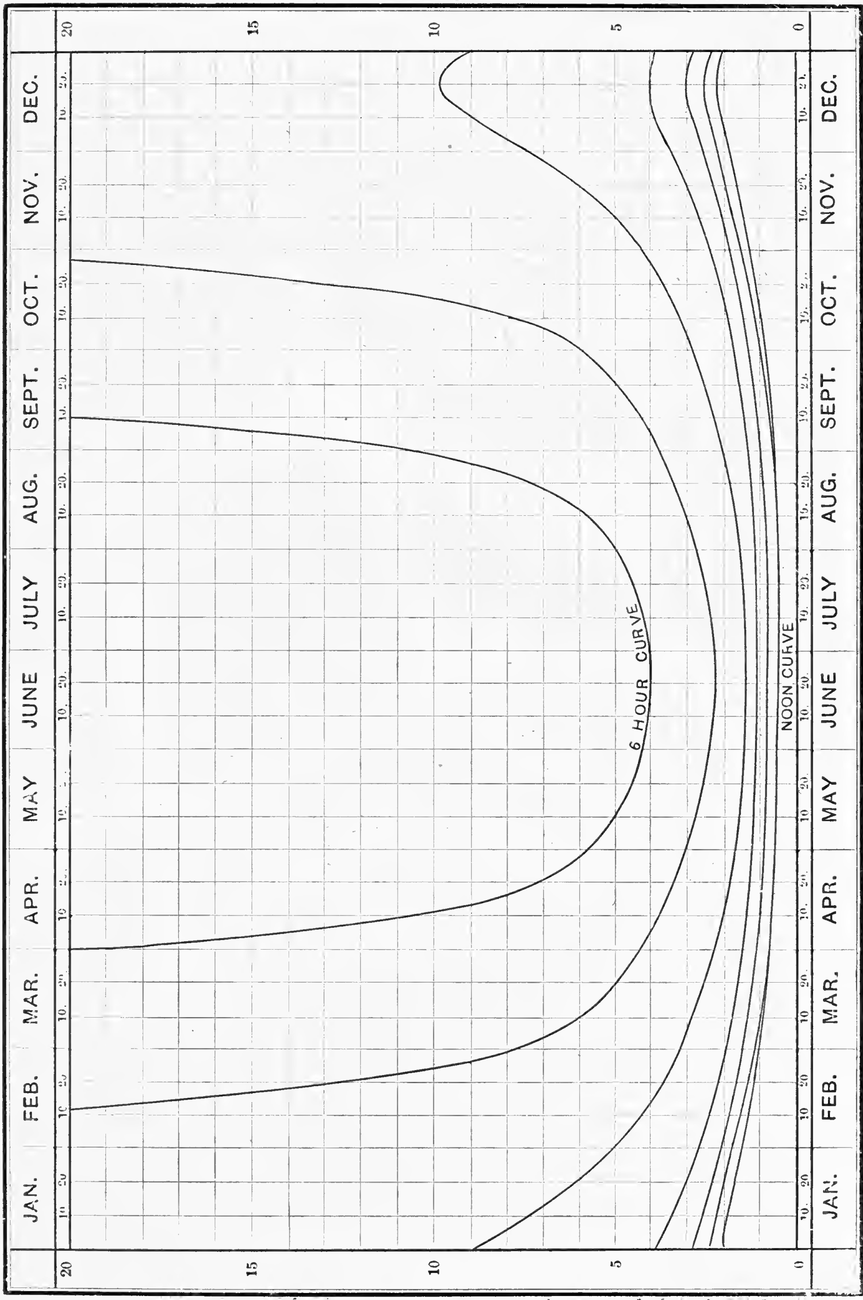
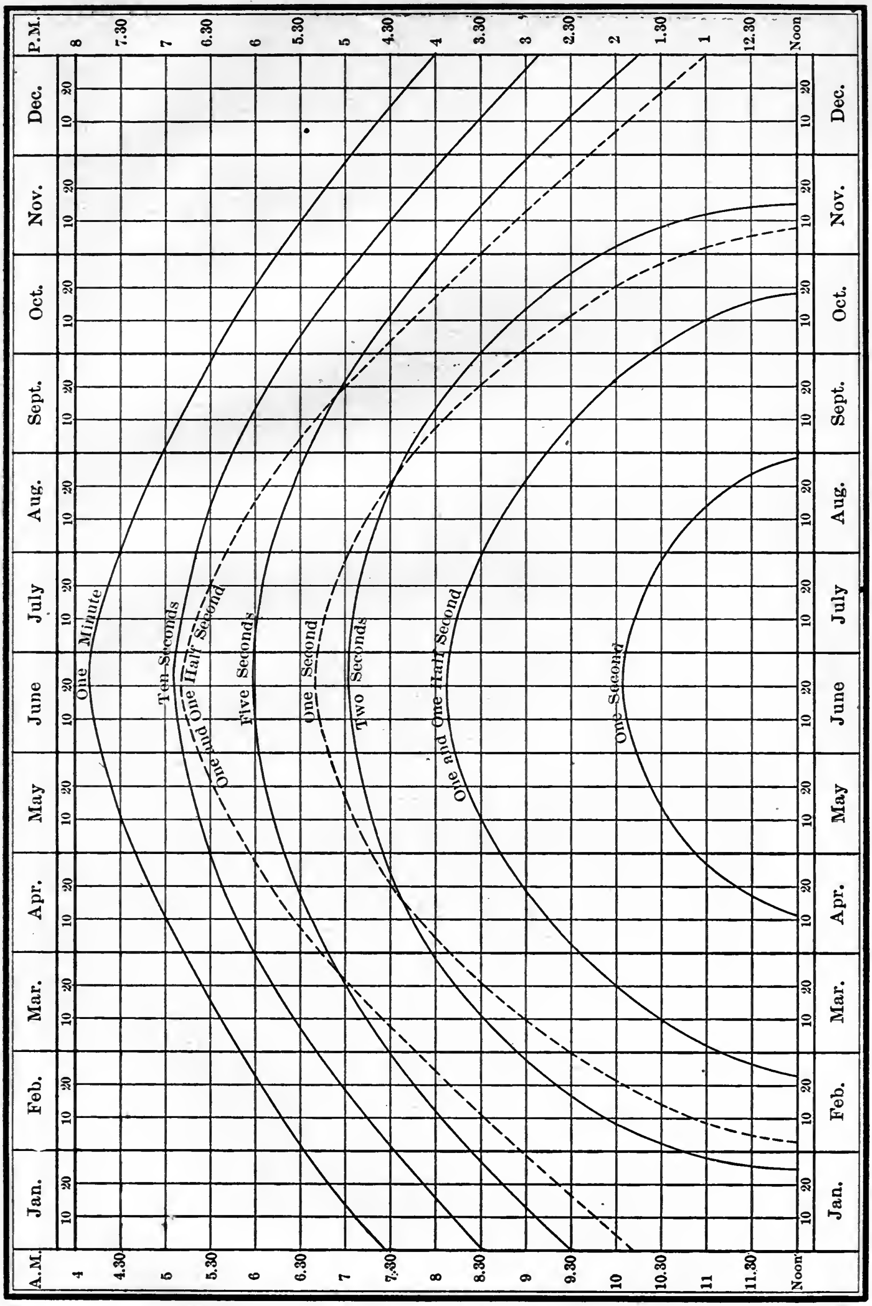
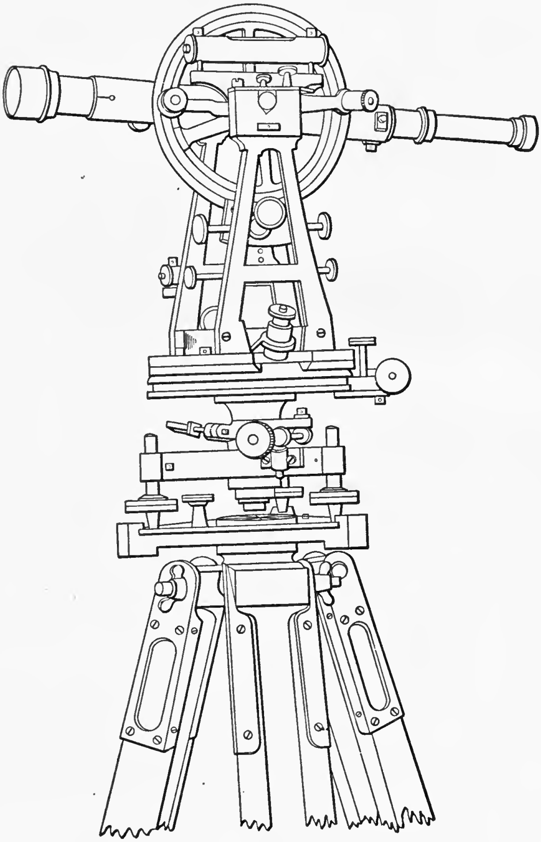
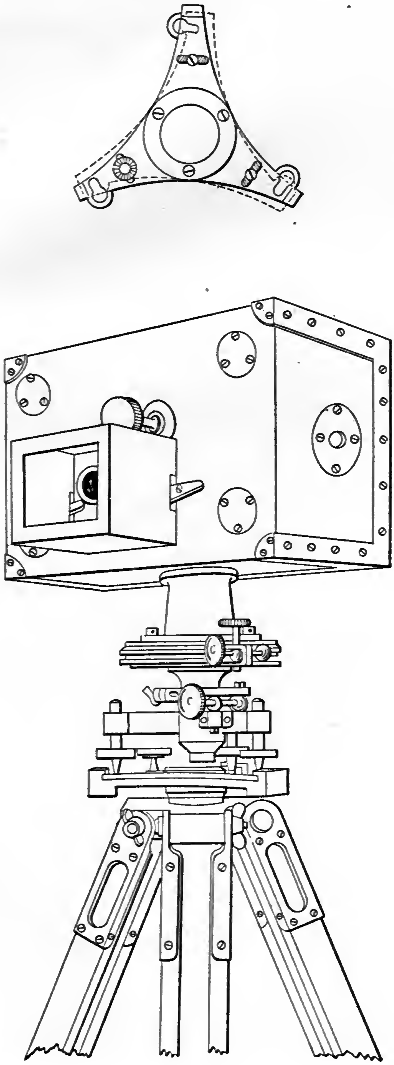


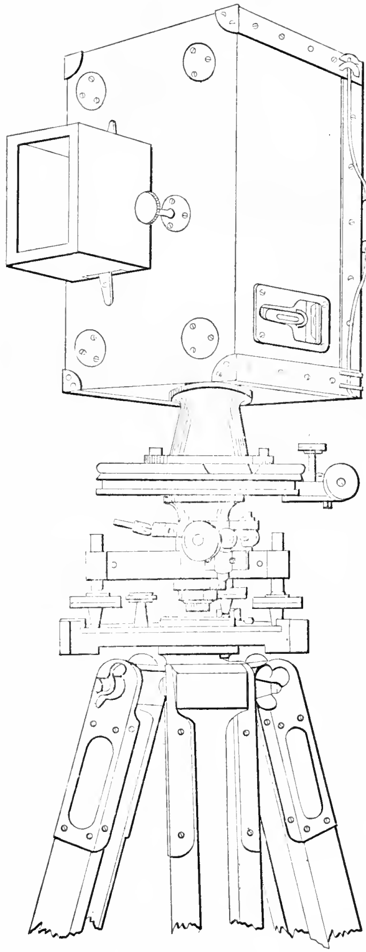
Fig. 179

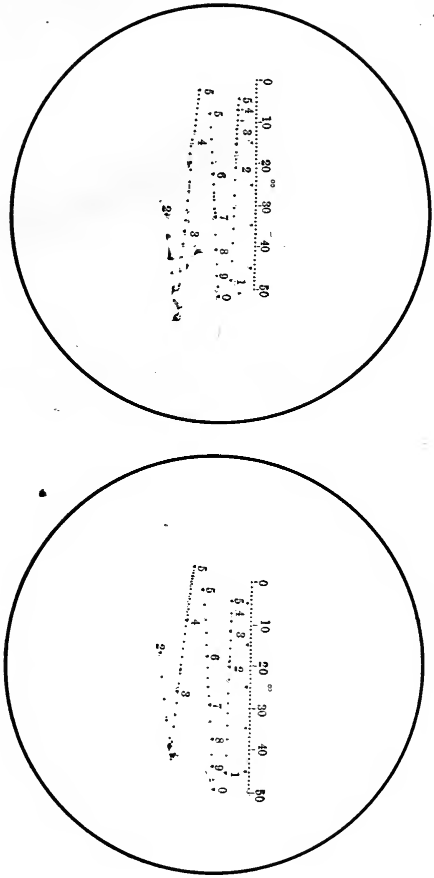

JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
20
15
10
5
0
6 HOUR CURVE
NOON CURVE

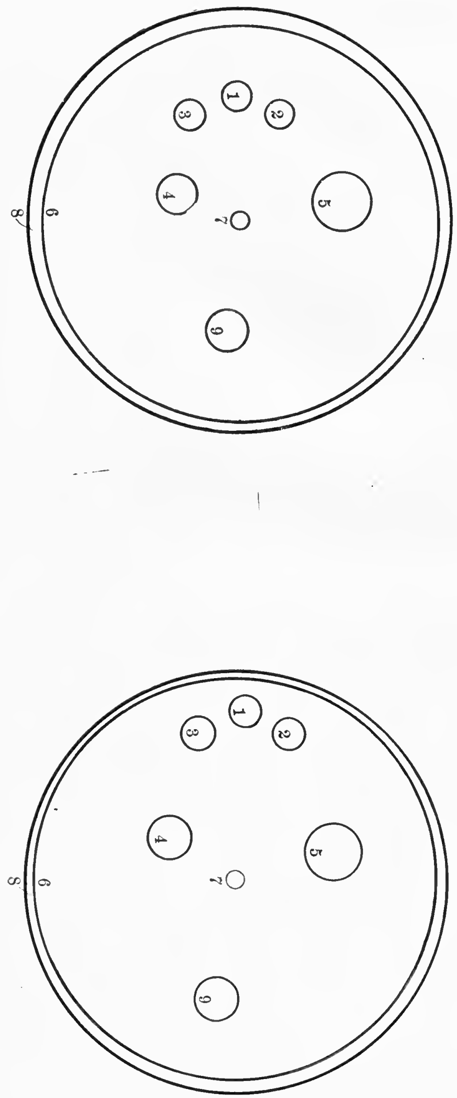

P.M.
8
7.30
7
6.30
6
5.30
5
4.30
4
3.30
3
2.30
2
1.30
1
12.30
Noon
A.M.
4
4.30
5
5.30
6
6.30
7
7.30
8
8.30
9
9.30
10
10.30
11
11.30
Noon
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
10
20
One Minute
Ten Seconds
One and One Half Second
Five Seconds
One Second
Two Seconds
One and One Half Second
One Second

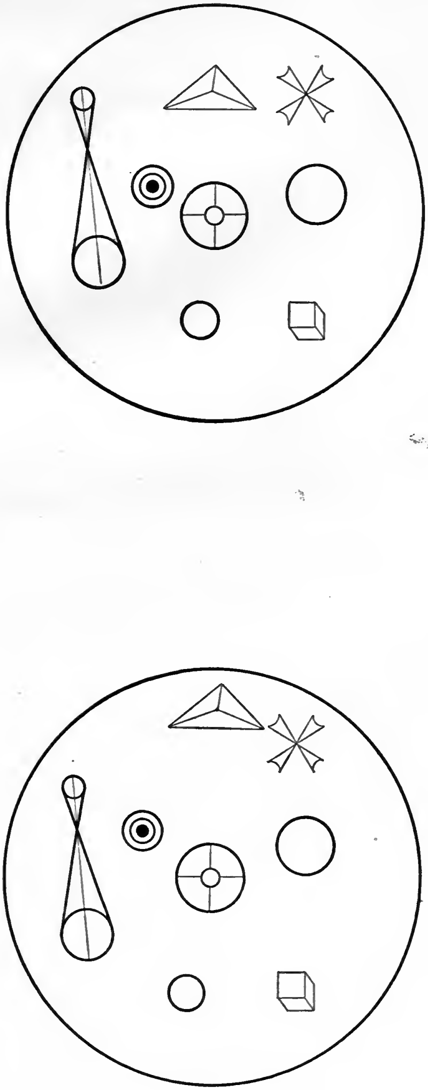


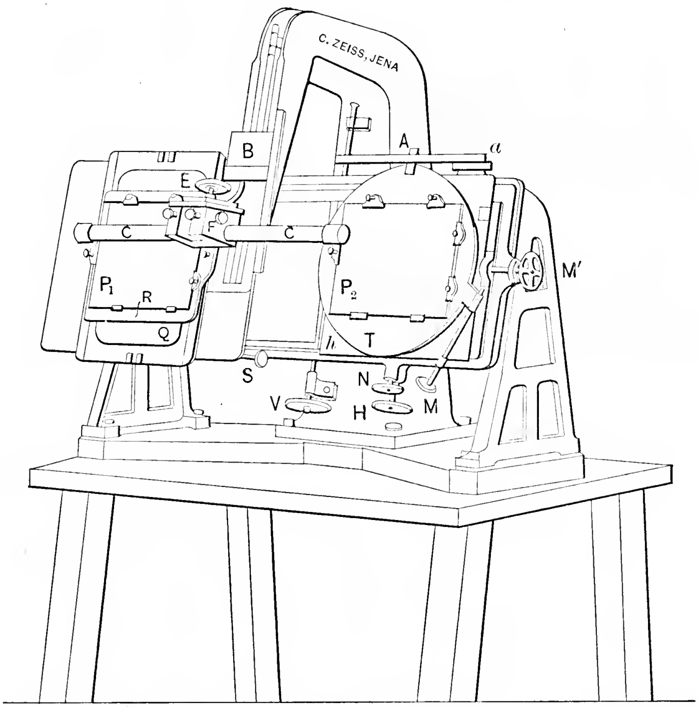







1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
7
8
9




C. ZEISS, JENA
A
a
B
E
C
F
C
P1
R
Q
P2
T
h
S
N
V
H
M
M′

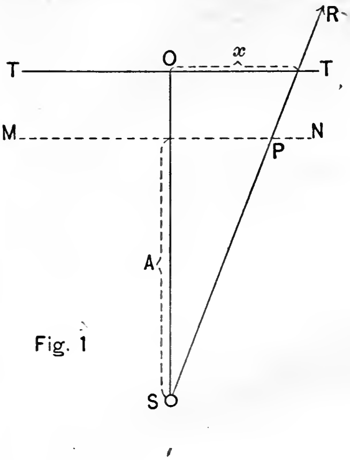


Fig. 1

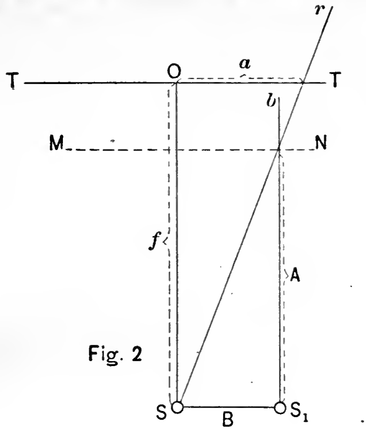


Fig. 2

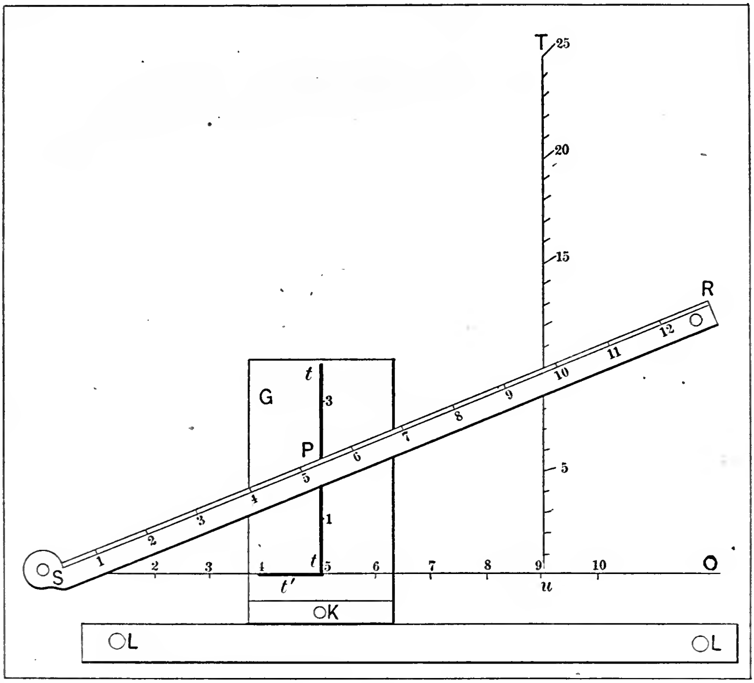


Fig. 3

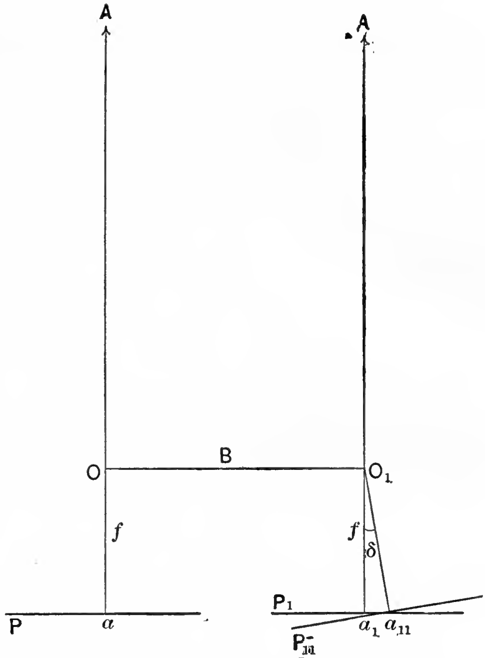

A
A
B
O
O_1
f
f
δ
P_1
P
a
a_1
a_{11}
P_{11}

Fig. 1

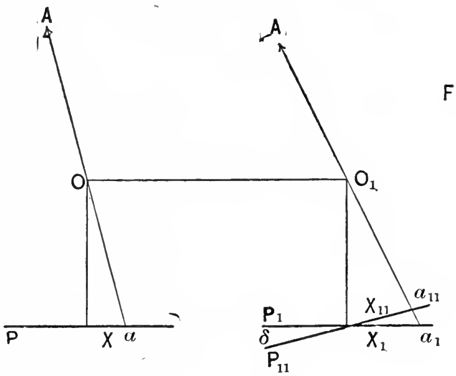
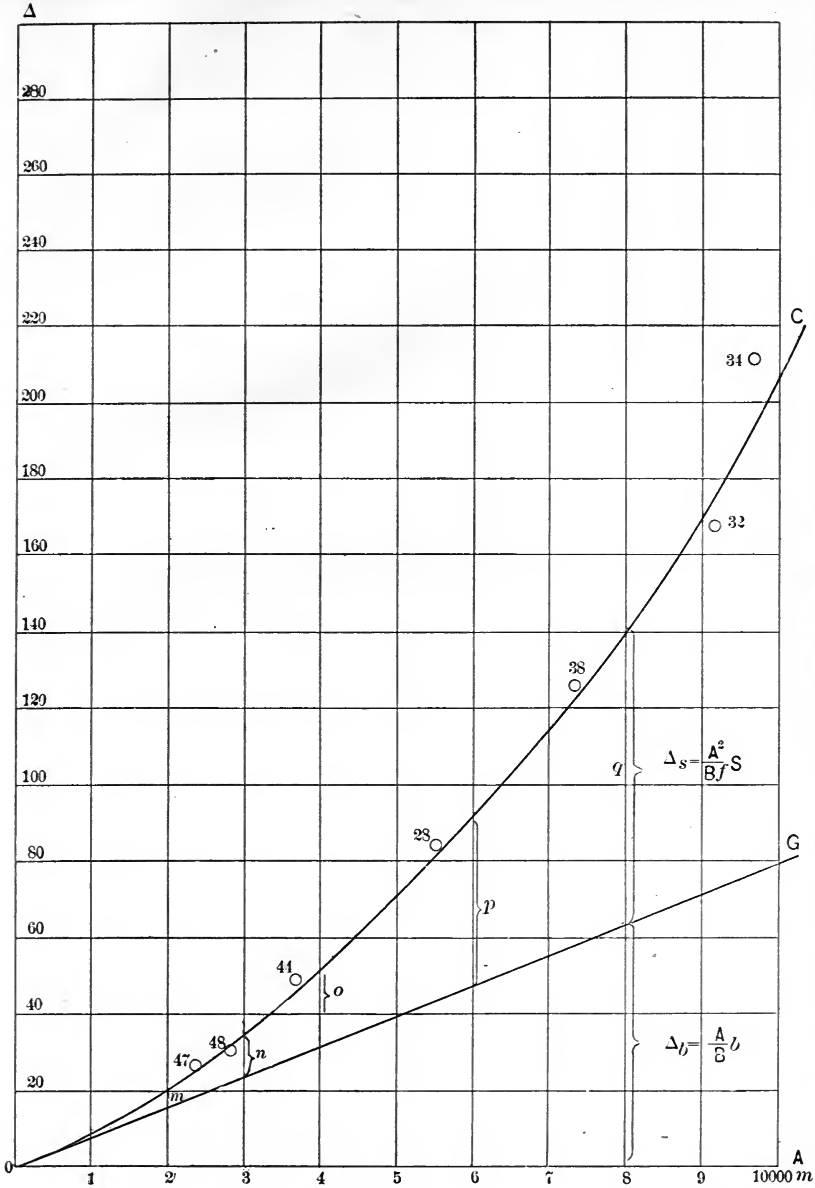

A
A
O
O_1
a_{11}
X_{11}
P_1
P
X
a
δ
X_1
a_1
P_{11}

Fig. 2


Δ
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10000 m
A
C
G
34
32
38
28
44
48
47
m
n
o
p
q
$\Delta_s = \frac{A^2}{Bf} S$
$\Delta_b = \frac{A}{B} b$

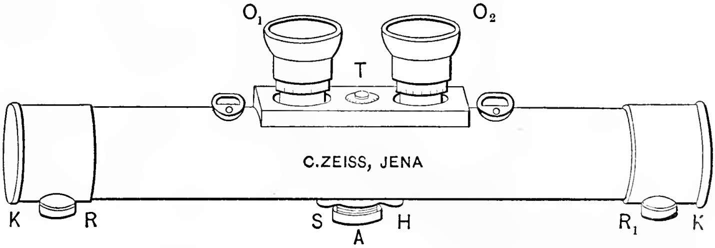

O1
O2
T
C.ZEISS, JENA
K
R
S
A
H
R1
K

Fig. 1

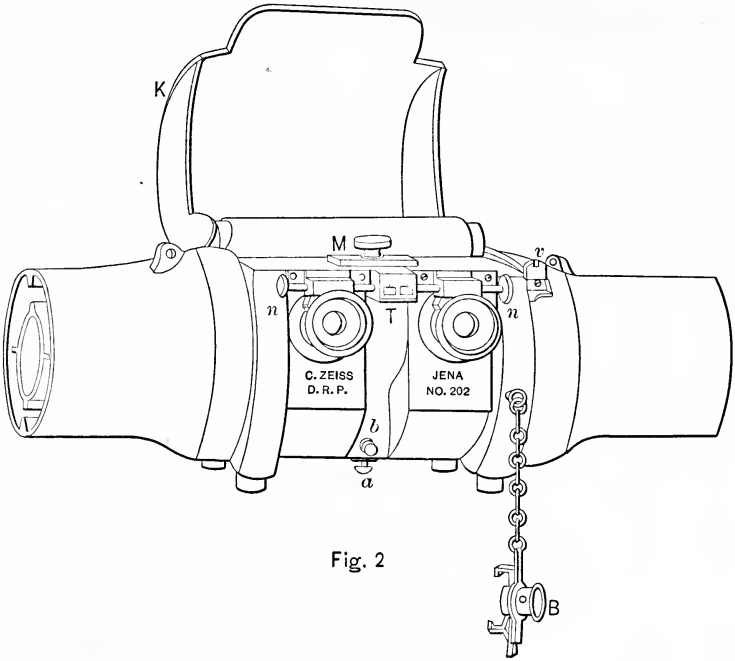
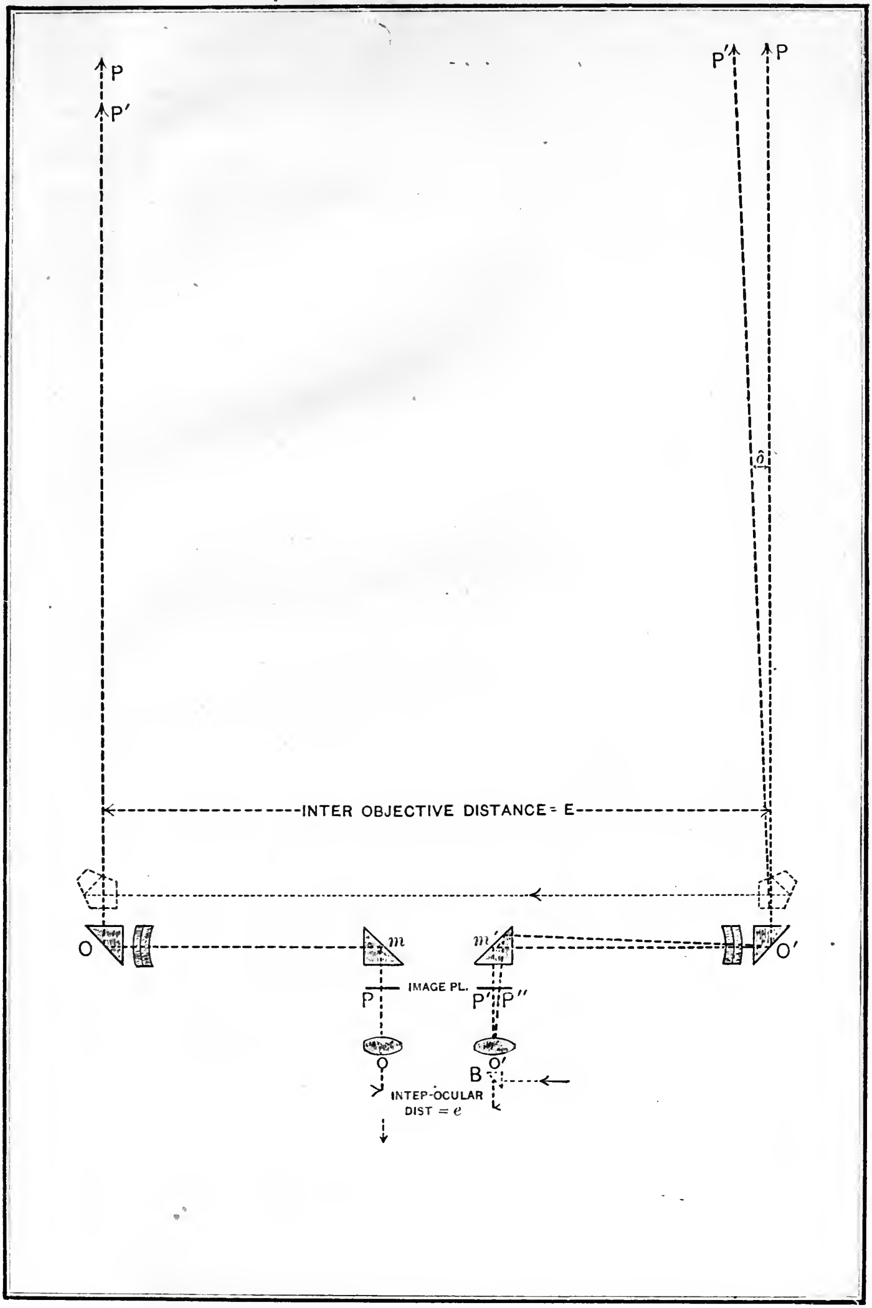

K
M
v
n
T
n
C. ZEISS
D. R. P.
JENA
NO. 202
b
a
B

Fig. 2


P
P′
P′
P
δ
INTER OBJECTIVE DISTANCE = E
O
m
m′
O′
IMAGE PL.
P
P′
P″
O
O′
B
INTEP-OCULAR
DIST = e